CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Plug Load Circuit Controls

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team October 2011

This report was prepared by the California Statewide Utility Codes and Standards Program and funded by the California utility customers under the auspices of the California Public Utilities Commission.

Table of Contents

Table of Figures

1. Purpose

The California investor owned utilities (IOU) Codes and Standards (C&S programs seek energy savings opportunities through supporting 2013 Title 24 development. This Codes and Standards Enhancement (CASE) report addresses controls of plug load in nonresidential buildings, especially those in office spaces.

Plug loads are becoming a major electricity end-use in office buildings. These loads are significant in term of both power density and power consumption, due to increased use of computer and other office electronic equipment. The practices of low ambient lighting designs also lead to increased use of task lights, which is one of the major components of office plug load.

According to the California Commercial End-Use Survey (CEUS) released in March 2006, interior lighting represents 26.4% of the electricity energy consumption in office spaces and is the highest electricity end-use. Office buildings compliant with the 2008 Title 24 minimum requirements can be assumed to have 0.9W/sf of installed overhead lighting and 0.2W/sf of installed task lighting. Hence, about 18% of the interior lighting power density is due to task lighting. In low ambient lighting designs, this ratio can be much higher. The 2008 Title 24 requires overhead lightings to be controlled, while task lightings are generally not controlled. As a result, total task lighting power consumption can represent a large share of interior lighting power consumption. Office equipment represents the third highest electricity end-use in California buildings; it accounts for about 19.2% of the total building electricity consumption. Despite penetration of newer and more efficient technologies, this electricity end-use is steadily increasing as the use of personal computers and other electronics devices in offices continues to grow. Forecasts by the Energy Information Administration's 2010 annual energy outlook predict a 36% increase in energy consumption by office personal computer (PC) equipment from 2010 to 2030, and a 65% increase for those by non-PC office equipment.

This CASE study investigates control strategies to reduce plug load power consumptions. The goal is to enable plug load equipment to be automatically shut off when they are not in use, so that overall power consumption can be reduced while equipment functions are not affected. Specified control technologies under investigation, such as timer controls and occupancy sensor controls, have already been required by 2008 Title 24 for general lighting controls in nonresidential buildings. Therefore, there is no technical barrier to expanding these control technologies to office appliances and equipment.

2. Overview

a. Measure Title	Plug Load Circuit Controls
b. Description	This proposal investigates the feasibility and cost-effectiveness of requiring automatic shut-off controls of electric circuits that serve plug loads, including task lightings, in office buildings. These controls enable connected task lights and plug loads to be automatically switched off when they are not in use. Uncontrolled circuits will still be available for appliances and equipment that cannot be or do not want to be interrupted. The capability of automatically shutting off plug load equipment connected to controlled circuits when not in use would result in electric energy savings. The proposal requires that two sets of circuit and associated receptacles be provided in the affected spaces; one is controlled and the other is not controlled. Occupants can select the proper receptacles according to the plug load functions. Since dual-circuit design is a preferred practice for office electrical system designs, the proposed changes have little impact to electric system wiring practice. This CASE study demonstrates that plug load circuits can be controlled using the existing lighting control technologies, such as timer and occupancy sensor controls that are required by 2008 Title 24 for general lighting automatic shut off controls. Technically, the proposed code changes simply require general lighting controls to be expanded to cover one set of plug load circuit. There is no technical barrier for the industry to implement the proposed measure. The proposed code changes do not impose any requirement on how plug loads should be connected or used. Rather, they ensure office buildings to be equipped with the proper control systems to enable reduction of unnecessary power consumption by plug loads.
c. Type of Change	The proposed requirements are mandatory for all office buildings as well as office spaces in other nonresidential building. As mandatory measures, these requirements do not affect the performance method and trade-off calculations. Similar to general lighting control requirements, they would require an acceptance test to ensure controls are correctly installed. In addition, the proposed changes require inspections to make sure receptacles are properly marked.

<table>
<tr>
<td>d. Energy Benefits</td>
<td>Energy savings are calculated for two prototype office buildings. As plug load circuit controls are not required in 2008 Title 24 and are not commonly installed, the baselines assumed plug load circuits were not controlled. The CASE study investigated three levels of control requirements. The final code change recommendation is based on the Level 2 control requirement. Energy savings corresponding to this level of requirements are provided in the table below for whole office building and for unit floor area. Energy savings are not affected by climate zones, while TDV electricity savings vary slightly among different climate zones. The proposed change does not have any natural gas savings. Detailed assumptions for energy savings calculations are provided in section 4.5. Description of the prototype buildings are provided in section 3.3.
<table>
<tr><th></th><th>Electricity Savings (kwh/yr)</th><th>Demand Savings (kw)</th></tr>
<tr><td>Per Building (Small Office - 10,000 sf)</td><td>4,900</td><td>1.97</td></tr>
<tr><td>Per SQFT (Small Office - 10,000 sf)</td><td>0.49</td><td>0.0002</td></tr>
<tr><td>Per Building (Large Office - 175,000 sf)</td><td>107,000</td><td>23.6</td></tr>
<tr><td>Per SQFT (Large Office - 175,000 sf)</td><td>0.61</td><td>0.00014</td></tr>
</table>
The statewide energy savings are estimated as below based on assumptions listed in section 4.8.
<table>
<tr><th>Electricity Savings (GWh/yr)</th><th>Demand Savings (MW)</th></tr>
<tr><td>34.3</td><td>9.2</td></tr>
</table>
</td>
</tr>
<tr>
<td>e. Non-Energy Benefits</td>
<td>Reduction in electrical power consumption reduces power plant emissions accordingly. Air quality will improve, related illnesses will be reduced and community health will be improved in general, which further increase societal productivity. Reduction in electrical power consumption also reduces the amount of land and resources that must be dedicated to a larger electricity infrastructure.</td>
</tr>
</table>

f. Environmental Impact

The potential adverse environmental impacts of this measure are negligible. Plug load circuit controls requires additional wiring and control equipment (occupancy sensors and control panels), thus slightly more copper and plastic usages.

The measure will contribute to reduction of power generation and size of the transmission and distributions system. This leads to small reduction in mercury emissions from coal-burning power plants, water consumption, and amount of land use for supporting a larger electricity infrastructure. The emission reductions of this measure are calculated by multiplying the electricity savings (kWh) by the emissions factors provided by California Energy Commission (CEC). The results are presented in the following table for both prototype office buildings.

Emission Impacts:

Prototype	NOX (lb/yr)	SOX (lb/yr)	CO (lb/yr)	PM10 (lb/yr)	CO2 (lb/yr)
Per Small Office	0.78	4.66	1.13	0.36	2844
Per Large Office	16.9	101.2	24.6	7.9	61804
Statewide	5414	32486	7882	2536	19,839,600

Material Increase (I), Decrease (D), or No Change (NC): (All units are lbs/year)

	Mercury	Lead	Copper	Steel	Plastic	Others (Identify)
Per Small Office	0.01	0.073	154	3.4	22	0
Per Large Office	0.11	0.83	2550	38	333	0
Statewide	74	550	1290000	25000	180000	0

There is no significant impact to water consumption and water quality by this measure.

g. Technology Measures

Measure Availability:

The proposed measure requires plug load control technologies that are required by 2008 Title 24 for general lighting controls. The CASE study demonstrated that compliance to the proposed code changes can be achieved through capacity expansion of the same control equipment used to meet the general lighting requirements.

Useful Life, Persistence, and Maintenance:

Lighting control equipment typically has a useful life of 15 years. Energy savings from the proposed measure will persist for the life of the building, if proper control equipment is replaced in the future. Lighting control equipment required by the proposed changes does not require maintenance, so we assume the same is true for plug load control equipment.

h. Performance Verification of the Proposed Measure	This measure will require acceptance tests that can be included in the currently established permitting and site inspection process, similar to those for general lighting controls. Specific requirements include: ◆ Verify that both controlled and uncontrolled receptacles are installed in the required spaces, and they are marked differently; ◆ In open office spaces, verify that circuit wire leads for future workstation furniture connection are marked as controlled and uncontrolled; ◆ Verify the required shut off controls function properly, following the acceptance test procedures for general lighting controls Once the initial acceptance tests are passed, consistent energy savings are expected.

i. Cost Effectiveness

Life cycle costs (LCC) per building floor area were calculated using the CEC Life Cycle Costing Methodology posted on the 2013 Standards website for each proposed measure. The CASE study investigated cost effectiveness of three levels of plug load controls. The results shown in the following table are for level 2 controls, which are the basis of the proposed code language. The post-adoption measure costs are not likely to change significant since the proposal is based on mature technologies used for general lighting controls. Therefore, they are not shown in the summary results table below. The proposed control requirements are based on controls for general lighting controls, so no additional maintenance efforts are needed. Details of the LCC analysis are included in Section 4.7.

a	b	c	f	g
	Measure Life (Years)	Additional Costs Current Measure Costs (Relative to Basecase) ($)	PV of Energy Cost Savings (PV$)	LCC c-f Based on Current Costs
Per Small Office Prototype(10,000 sf)	15	$2,638	$9,433	($6,796)
Savings per square foot(Small Office)	15	$0.26	$0.94	($0.68)
Per Large Office Prototype (175,000 sf)	15	$33,250	$206,373	($173,123)
Savings per square foot(Large Office)	15	$0.19	$1.18	($0.99)

j. Analysis Tools	Plug load energy consumption is not covered by any Title 24 reference methods. A spreadsheet tool was developed following energy analysis method described in the Methodology section to assess measure energy savings. The proposed measure is a mandatory requirement, therefore, building energy simulation tool was not needed to quantify energy savings for performance trade-off calculations.

k. Relationship to Other Measures	The proposed measure is related to all other office lighting control and electric system measures because plug load circuit controls need to be integrated with the rest of the building lighting control systems. The proposed measure is also important to measures that encourage low ambient lighting strategies in that it will make sure energy savings achieved with low ambient lighting are not offset by increased task lighting usage when occupants are away from their desk.

3. Methodology

This section describes the methodology that we followed to assess control strategy feasibility, energy savings, incremental costs, and cost effectiveness of the proposed code change. The key elements of the study methodology are as follow:

- Plug load characteristics study
- Control technologies market study and industry practice survey
- Prototype building development
- Energy Savings Analysis
- Cost Analysis
- Cost-effectiveness Analysis
- Statewide energy savings analysis
- Stakeholder Meeting Process

3.1 Plug Load Characteristics Study

The first step of the study was to understand office building plug load characteristics in terms of installed power densities and operation patterns. Such information was needed to determine if and how plug loads can be controlled and the amount of power that can potentially be reduced through controls. The CASE study team conducted literature reviews in order to collect relevant information. Different sources were reviewed and analyzed in order to provide a comprehensive understanding of the subject.

3.2 Market Assessment

The general concept of this proposal is to require plug loads to be automatically shut off by time switchers or occupancy sensors when they are in use. To demonstrate the feasibility of this concept, the CASE study conducted market studies to identify commercially available control products and to explore control system design options. Market study results of available control products were used to develop compliance options, and product costs were used to support the cost analysis of the proposed control requirements.

This market assessment encompassed two efforts:

- Control technologies market study
- Industry practice assessment

The market study started with literature research to understand existing practices and technology development associated with plug load controls. This effort was carried out in conjunction with literature research on office plug load characteristics study.

Many plug load control studies focused on soft-wired control technologies, e.g. task lighting with embedded occupancy sensor and power strips with occupancy sensor or timer control capabilities. These are effective plug load control technologies and are especially cost effective for plug load control in existing buildings. They are not, however, suitable for Title 24 regulation. This CASE study seeks hardwired control strategies to be implemented in new construction buildings.

The literature study and initial survey revealed that hardwired plug controls had very small market penetration and that little was published on this topic. In response, the CASE project team shifted market study efforts towards product research and control strategy development by interviewing industry practitioners. A broad range of lighting control and circuit control products were reviewed. The project team conducted extensive discussion with lighting control and system furniture manufacturers to examine how hardwired plug load circuit controls can be implemented. The CASE team further surveyed electrical designers, contractors and system furniture manufacturers using an online survey and through phone calls. The survey aimed at collecting industry consensus on following issues:

- Lighting and circuit control practices and products
- Feasibility of potential plug load control requirements
- Office electric circuit wiring design practices
- Integration of plug load controls with office furniture systems

The project staff further interviewed authors of relevant studies and projects to obtain detailed technical information, to seek additional control strategies and design options, and to identify implementation and operation issues.

3.3 Building Prototype Development

The CASE team developed two building prototypes (a small office building and a large office building) to assess the energy savings, cost, and cost-effectiveness of the proposed plug load control requirements. The two office building prototypes were based on the Database for Energy Efficient Resources (DEER), which classified the office building stock into two categories, small and large, using a building square footage threshold of 30,000 sf. An office layout was developed for each prototype based on typical office building design and was checked by registered architects.

3.4 Energy Savings Analysis

The CASE study separated plug load into two categories, controllable and uncontrollable, according their functions. Once controllable plug loads are plugged into receptacles that are connected to controlled circuits, they can be automatically shut off when they are not in use. The amount of energy savings depends on three elements:

- Plug load density - how many plug loads are connected to controlled receptacle, which are receptacles that are connected to a controlled circuit
- Control period - when plug loads can be switched off
- Power status - the average power consumption when they are switched off.

Installation densities for each type of controllable plug loads, along with their and power consumption characteristics were determined based on task lighting and plug load characteristics study. The number of plug loads installed in each building prototype was further estimated based on prototype building sizes and detailed space configurations, such as number of private offices and conference rooms.

There are several scenarios when controllable plug loads can be switched off. They are referred as control periods in the study and they include the following:

- Non-Business hours
- Business hours – the occupant is away from desk
- Business hours – the occupant is out of office
- Business hours – the conference room is empty (for conference room plug loads only)

Control period depends on office operation and occupancy presence schedule. Control periods were developed based on assumptions of average office operation schedules. Central time switch controls can shut off plug loads according to a fixed schedule when all occupants are expected to be out of office, therefore timer controls only work during non-business hours. In the case of occupancy sensor control, additional savings can be achieved when an occupant is not at his/her desk during business hours Similarly, occupancy sensor control in conference rooms can achieve additional savings when the conference room is vacant. Therefore, occupancy sensor controls are effective for all above control period.

Power status of task lighting and other controllable plug loads during different control periods, i.e. business and non-business hours were based on information collected through plug load characteristics study, described in section 3.1.

The CASE team evaluated energy savings for both the small and large office building prototypes. Different levels of control were considered based on different combinations of time switch controls and occupancy sensor controls.

3.5 Cost Analysis

This code change proposal seeks to expand existing lighting control systems for general lighting in office buildings to control plug loads. The 2008 Title 24 general lighting automatic shut off control requirements were used as the baseline for building circuit control system design. Different levels of potential plug load requirements were developed as upgrades to building general lighting control systems. The incremental costs of the proposed code changes area system upgrade costs associated with the following components:

- Cost of control equipment upgrade, installation, configuration, and maintenance
- Cost of additional wiring, if any

Control equipment costs depend on the number plug load circuits to be controlled, which further depends on prototype building circuit wiring configurations. Different office building wiring practices were considered to generate a range of cost estimate. This approach effectively demonstrate code change feasibility with realistic compliance examples.

Control equipment costs were obtained from manufacturers' distributors as part of the control technology market study discussed above. Labor and material costs for installation, configuration and additional wiring were estimated based on RS Means Cost Works Online Construction Cost Data.

3.6 Cost Effectiveness Analysis

The CASE team calculated lifecycle cost analysis using methodology explained in the California Energy Commission report *Life Cycle Cost Methodology 2013 California Building Energy Efficiency Standards*, written by Architectural Energy Corporation, using the following equation:

$$\Delta LCC = Cost\ Premium - Present\ Value\ of\ Energy\ Savings$$ [1]

$$\Delta LCC = \Delta C - (PV_{TDV\text{-}E} * \Delta TDV_E + PV_{TDV\text{-}G} * \Delta TDV_G)$$

Where:

ΔLCC	change in life-cycle cost
ΔC	cost premium associated with the measure, relative to the base case
$PV_{TDV\text{-}E}$	present value of a TDV unit of electricity
$PV_{TDV\text{-}G}$	present value of a TDV unit of gas
ΔTDV_E	TDV of electricity
ΔTDV_G	TDV of gas

A 15-year lifecycle was used as per the LCC methodology for nonresidential lighting control measures. LCC calculations were completed for two building prototypes, in all sixteen (16) climate zones analyzed, for high, low, and average load shed rates. This provided a range of cost effectiveness to accommodate for varying scenarios.

3.7 Statewide Energy Savings

Statewide energy savings were calculated by multiplying unit energy savings (savings per square foot) by the CEC's forecast of new construction floor area of office buildings. Office spaces in other types of buildings are also estimated and included in estimating statewide energy savings. Peak demand savings were estimated as the average load (kW) reduction during summer peak hours, which are defined as 12pm – 6 pm in July through September, according to CPUC treatment of demand savings for IOU energy efficiency programs.

The proposed the change only enables building occupants to control their plug loads, but not require them to plug their controllable plug loads equipment into controlled receptacles. The statewide energy savings depends on how many plug load devices are plugged into controlled receptacles by building occupants. We'd also expect that it will take some time for building occupants and operators to get used to the new receptacle system so that more and more plug loads will be connected to controlled receptacles. The CASE study estimated rates of plug load control for each plug load category. An

[1] The Commission uses a 3% discount rate for determining present values for Standards purposes.

overall plug load control implementation rate was estimated accordingly and was used to assess realistic statewide energy savings.

4. Analysis and Results

This section presents the data collected and results of analysis according to approaches laid out in the methodology section.

4.1 Plug Load Characteristics Study

The CASE team identified and reviewed a list of publications related to plug load characteristics. Detailed references of these reports are provided in the Bibliography and Other Research section. Two studies, one from the Lawrence Berkeley National Laboratory (LBNL) and one from ECOS Consulting, provided the most comprehensive and up-to-date data of office plug load installation density, usage patterns, and energy consumption states.

LBNL conducted series of field measurement studies and analysis of equipment density, powers, and usage patterns of miscellaneous office equipment. The study (referred to as the LBNL Study in following sections) focused on characterizing after-hour power states of office plug loads. It was published in two papers, "After-hours Power Status of Office Equipment and Energy Use of Miscellaneous Plug-Load Equipment." and "Field Surveys of Office Equipment Operation Patterns". The PIER research conducted by ECOS Consulting (referred to as the ECOS Study in following sections) monitored power consumption and status of plug load devices in 25 commercial offices in 2007 and 2008. The research metered plug load devices and recorded power, current, voltage, and power factor over a two-week period at one-minute intervals. In total, the team inventoried nearly 7,000 plug load devices and collected meter data from 470 plug load devices.

The CASE study developed assumptions of plug load densities and usage patterns for energy savings analysis based the field data provided by these two studies.

4.2 Stakeholder Meeting Process

All of the main approaches, assumptions and methods of analysis used in this proposal have been presented for review at public Stakeholder Meetings.

At each meeting, the utilities' CASE team invited feedback on the proposed language and analysis thus far, and sent out a summary of what was discussed at the meeting, along with a summary of outstanding questions and issues.

Records of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodes.com. Stakeholder meetings were held on the following dates and locations:

- Control and DR Stakeholder Meeting: July 7th, 2010, San Ramon Conference Center, San Ramon, CA
- Lighting Stakeholder Meeting: February 24th, 2011, UC Davis Alumni Center, Davis CA

In addition to the Stakeholder Meetings, the CASE team contacted representative of diverse organizations involved in projects or code proposals related to plug load control such as ASHRAE and NBI.

4.2.1 Office Plug Load Definition

In general, office plug loads include task lights and other office and personal equipment and devices. Task lighting devices are a major component of office plug load. Their installed density usually varies between 1 and 2 lighting fixtures per office workstation, which is either a private office space or an open-space office cubicle. The 2008 Title 24 has a definition for task light in section 100:

> "Task lighting is lighting that is designed specifically to illuminate a task location, and that is generally confined to the task location."

There is no specific Title 24 requirement for task lighting controls. The 2008 Title 24 requires office space lighting power density (LPD) to be no more than 1.1 W/sf. This requirement was developed based on the assumption that installed task lighting LPD is about 0.2 W/sf and overhead lighting LPD is 0.9 W/sf. to reach the maximum allowed power density of. Low ambient lighting strategies, which reduce overhead lighting LPDs, tend to increase task lighting LPDs and usages.

For other office plug loads, taxonomy and data from the LBNL Study and ECOS Study were used. According to the LBNL Study, office plug loads can be broken into two categories: office equipment and miscellaneous equipment.

Office equipment refers to electronics products primarily designed for office work. The ECOS Study further separates office equipment into computers and monitors, and office electronics. For the purpose of this analysis, it was further classified into the following categories:

Miscellaneous equipment refers to plug load devices that are typically portable, often occupant-provided units whose number, power consumption and usage patterns depend more on occupants.

Combining the results from the ECOS Study and LBNL Study, the most common office plug loads are listed below:

- Task lighting:

  Under-cabinet light, table lamp

- Office equipment

  Computer & Monitor:

  - Computers: desktop, laptop (notebook or mobile), thin clients
  - Monitors: cathode ray tube (CRT), and liquid crystal display (LCD)

  Office electronics

  - Imaging: printers (inkjet, laser, wide format), fax machines, copiers, scanners, multi-function devices (inkjet, laser)
  - Computer Peripheral: computer speakers

- Miscellaneous equipment

  Audio/Visual: television, DVD player, video projector, speakers, subwoofers, CD player, portable stereo, portable CD player, table radio

  Telephone: speakerphone, answering machine, phone jack

Kitchen Equipment: refrigerator, coffee maker, coffee grinder, toaster oven, microwave oven, vending machine, water dispenser, hot beverage dispenser

Others: portable fan, portable space heater, stapler, electric typewriter, shredder, adding machine

4.2.2 Controllable and Non-controllable Plug Loads

The CASE study does not propose Title 24 changes to regulate installation and usages of plug loads, which should be decided by building owners/operators/occupants based on their business and/or personal needs. Energy savings should come from active controls during times when plug loads are not in use. Some plug-load devices, e.g. fax machines and network equipment, cannot be switched off even during non-business times due to business operation requirements. They are classified as non-controllable plug load. Controllable plug loads are those that can be switched off either when the occupant is away from the workstation or when the office is closed for business. Controllability of certain plug load equipment is hard to be determined. For example, battery chargers can be switched off when the connected battery is fully charged, however, it is not feasible to require the control to determine if the charging is complete. For energy savings evaluation, this CASE study took a conservative approach and only classified those that can be safely switched off without affecting any intended functions as controllable plug loads.

Figure 1 provides a list of non-controllable equipment. They are not included in the energy savings analysis.

Plug Loads	Rationale
Desktop, laptop, and thin client computers	Need to stay on for remotely access and/or for software update during non-business hours
Ethernet hub or switch	Need to support connected computers
Phone, fax	Need to receive messages/fax all the time
Refrigerator, clock, battery chargers	Need to provide continuous operation

Figure 1 Examples of Non-controllable Plug Loads

Figure 2 provides a detailed list of controllable plug loads, which include task lights. The figure also indicates suitable control technologies, which depend on where in the office building the plug load can be found: workstation (private office or cubicle), conference room, copy room, or kitchen. Workstations and conference rooms allow occupancy sensor controls where devices can be switched off whenever the space is unoccupied. Kitchen and copy room appliances cannot be disrupted during business hours, because most of those applications can be in operation even without presence of any occupants. Plug load shut-off controls in these spaces are better to set to be during non-business hours with a time switch control. Detailed discussion on control technologies will be provided in following sections.

In order to support both controllable and non-controllable plug loads, two separate sets of receptacles are needed. The electric circuits connected to one set of receptacles are controlled, in a similar way to general lighting circuit controls, to achieve automatically shut off. This set of receptacles is called controlled receptacles and are marked differently from those not be controlled. When controllable plug loads are connected to controlled receptacles, energy savings will be achieved. Non-controllable plug loads are connected to un-controlled receptacles so that their services are not disrupted. Similar to general lighting shut off controls, building occupants should have easy access to manual switches, which can be the same ones used for general lighting controls, to override the shut off controls.

In practice, building occupants have the choice to decide which plug loads are to be plugged into controlled receptacles.

Plug Load	**Time Switch Control**	**Occupancy Sensor Control**	
		Private Office / Cubicle	**Conference Room**
Task Lighting			
Under Cabinet Light	Y	Y	
Table Lamp	Y	Y	
Monitor			
CRT	Y	Y	
LCD	Y	Y	
Printing/Imaging Equipment			
Laser MFD	Y		
Inkjet MFD	Y		
Laser printer	Y		
Inkjet printer	Y		
Wide Format Printer	Y		
Document Scanner	Y		
Audio /video			
Television, LCD	Y		Y
DVD player	Y		Y
Video Projector	Y		Y
Speakers	Y		Y
Subwoofer	Y		Y
CD Player	Y		Y
Computer Speakers	Y	Y	Y
Portable Stereo	Y	Y	
Portable CD player	Y	Y	
Table Radio	Y	Y	
Other			
Adding machine	Y		
Shredder	Y		
Stapler	Y		
Typewriter, Electric	Y		
Fan, portable	Y	Y	

Space heater, portable	Y	Y	
Kitchen Appliance			
Coffee Grinder	Y		
Coffee Maker	Y		
Toaster oven	Y		
Microwave oven	Y		
Water dispenser	Y		
Vending machine	Y		
Hot beverage dispenser	Y		

Figure 2 Plug Loads that can be controlled by a Time Switch or by an Occupancy Sensor

4.2.3 Operation Mode / Power Status

Most office equipment has different operational modes, or power states. This study adopts the ECOS Study definitions of five different power states, listed below:

- **Disconnected:** In this state, a device does not draw any power. This could occur when a device is unplugged, turned off with a hard switch, or turned off via a surge protector or plug strip.
- **Standby:** This state corresponds to the lowest steady power drawn, and usually occurs when a device doesn't perform its primary function or when it is switched off with a soft switch but is still plugged.
- **Sleep**: This mode defines a power state between standby and idle. It exists for devices with power-saving features.
- **Idle**: A product operates in idle when it is prepared to perform its intended function, but is not doing so.
- **Active**: A device is performing its intended function. In some cases, products may have more than one intended function and therefore a wide range of active mode power. For example, a multifunction device demands different power levels for scanning, printing, and copying; however, when it is performing any of these functions, the device is in active mode.

In the ECOS Study, a product was considered to be in a power state when it spent a significant and continuous period with its power consumption in a narrow range. An operating mode could include one or more power states, and may have also included fluctuating power levels that were not considered power states.

Figure 2 provided average power, as well as typical installation density in small and large offices (defined by a 30,000 square footage threshold), for each controllable plug load based on data provided by the LBNL Study and the ECOS Study. The equipment density reflects averaged number of devices installed per occupant.

Plug Loads	**Active (W)**	**Idle (W)**	**Sleep (W)**	**Standby (W)**	**Density (unit/person)**		**Power Density (w/sf)**	
					Small Office	**Large Office**	**Small Office**	**Large Office**
Task Lighting								
Lamp, Desk attachment	35.4	23.2		0.57	0.5	0.5	0.06	0.07
Lamp, Table	41.7	13.4		0.91	1	1	0.14	0.17
Monitor								
CRT	70.6	64.2	45.9	2.6	0.21	0.23	0.05	0.07
LCD	34.2	26.4	6.19	0.88	0.99	1.07	0.11	0.15
Printing/Imaging								
Laser MFD	75.7	26.1	5.44	5.45	0.01	0.01	0.00	0.00
Inkjet MFD	26.0	11.1		4.66	0.04	0.04	0.00	0.00
Laser printer	130.1	19.0		11.4	0.26	0.26	0.11	0.14
Inkjet printer	64.0	6.75	4.68	2.69	0.24	0.2	0.05	0.05
Wide Format Printer	86.8	28.6		5.62	0.048	0.04	0.01	0.01
Document Scanner	10.1			4.03	0.05	0.05	0.00	0.00
Audio /video								
Television, LCD	58.2			3.14	0.04	0.04	0.01	0.01
DVD player	80.0			1.28	0.02	0.04	0.01	0.01
Video Projector	181.9		9.76	4.56	0.02	0.04	0.01	0.03
Speakers	32.0	10	3	1	0.04	0.08	0.00	0.01
Subwoofer	200.0	6.96			0	0.01	0.00	0.01
CD Player	8.3			2.06	0	0.02	0.00	0.00
Computer Speakers	6.0	2.43		1.66	1	1	0.02	0.02
Portable Stereo	7.5	3.31		0.88	0.02	0.01	0.00	0.00
Portable CD player	18.0	2.95		1.27	0.02	0.01	0.00	0.00
Table Radio	2.8			1.4	0.2	0.2	0.00	0.00
Other								
Adding machine	3.6	3.57		1.58	0.04	0.04	0.00	0.00
Shredder	78			0.77	0.04	0.02	0.01	0.01
Stapler	2	0.81		1.22	0.04	0.02	0.00	0.00

Typewriter, Electric	7			3.38	0.02	0.02	0.00	0.00
Fan, portable	30			0.63	0.1	0.2	0.01	0.03
Space heater, portable	938			1.03	0.1	0.2	0.31	0.78
Kitchen Appliance								
Coffee Grinder	120.0	1.25		0.21	0.2	0.01	0.08	0.01
Coffee Maker	464	40.3		1.77	0.1	0.01	0.15	0.02
Toaster oven	1058			0.03	0.04	0.02	0.14	0.09
Microwave oven	1620			3	0.08	0.02	0.06	0.14
Water dispenser	90			1	0.08	0.01	0.00	0.00
Vending machine	205			1	0.04	0.01	0.00	0.01
Hot beverage dispenser	1650			75	0	0.01	0.03	0.07

Figure 3 Plug Load Power States and Typical Installation Density

4.3 Market Assessment

The goal of the market study was to demonstrate feasibility and product availability of the proposed plug load control requirements. The market study also provided information to develop baseline designs for the cost analysis. The CASE study team investigated different levels of controls, which provide different potentials of energy savings.

4.3.1 Plug Load Control Standards

Both ASHRAE 90.1 and International Green Construction Code (IgCC) have adopted codes for plug load controls. The ASHRAE 90.1 Lighting Subcommittee developed a CMP to 90.1-2007, modifying Addendum "bs" section 8.4.2, labelled "Automatic Receptacle Control". The IgCC technical requirement was developed in the framework of soft-wire control technologies such as timer or occupancy sensor on plug strips or smart strips rather than hard wiring control technologies.

Code language for both organizations can be found in Appendix I: ASHRAE and IgCC Plug Load Control Standards.

4.3.2 Control Products

In general, electrical circuits dedicated to task lighting and other plug loads can be shut off in the same way as general lighting shut off controls. Some manufacturers already promote lighting control products for plug load controls to respond to the growing market demand for reducing plug load energy consumption. Electrical designers, contractors, building managers, and building officials are familiar with the design, installation, and operation of circuit controls due to various existing lighting control code requirements and practices. Hence, there are no infrastructure or market or behavior barriers to the expansion of general lighting controls to cover plug load circuits/receptacles. Both time switch and occupancy sensor controls can be applied to plug load controls. Manually override can be achieved with the same type of dry contact signal or by sharing the same override switches for general lighting controls.

The following sections describe the types of control products that are commercially available to demonstrate feasibility of the proposed measure. Lists of control products from selected manufacturers are only intended provide real examples of products. The CASE study does not endorse any products from the those manufacturers and does not suggest the list products are the only ones that are in compliance with the proposed control requirements.

Time Switch Controls

Time switch controls can be achieved with lighting control panels or controllable breaker panels. These control panels are usually centrally located to serve a large zone of a building. Therefore, the CASE study also refers to the control technology as the central time switch control, although other non-central located control products can also achieve the same function.

Lighting Control Panels

Lighting control panels essentially use relays to switch on and off 120V or 277V lighting circuits. Most manufacturers indicated that they can be used to control general 120V circuits for plug load. These relays can be controlled by an astronomical timer clock, building management system signal, occupancy sensors or other inputs. Most control panels currently on the market are compatible with BACNet, LonWorks, DMX512, and other building management communication protocols. They all come with manual override to ensure services can be provided whenever needed, and most of them are Title 24 compliant certified. These panels usually come in three sizes, with the most common sizes being 8, 30 and 48 channels. Therefore, the number of circuits that can be controlled by one panel ranges from 8 to 48. Many buildings required more than one control panels. In this case, panels can be networked, with only one logic controller for the whole network to avoid controller logic redundancy and to reduce system cost. The number of panels allowed in a network varies from 10 to 128 depending on the manufacturer and the product line. Most of the products can deal with 120V and 277V mixed loads using a voltage barrier, which is usually a plastic plate to separate 120V and 277V circuits. Therefore, overhead lighting and plug controls can be achieved using the same control panel. Task lighting and plug load control can be implemented by increasing the number of relays in the existing lighting control panel for control circuits serving controlled receptacles.

Controllable Breaker Panels

Controllable breaker panels integrate circuit breakers for power surge protection and switch control into one panel, so the system demands less space for installation. A controllable breaker panel can have mixed number of controlled and uncontrolled channels. Usually, the number of controlled breakers in a panel comes in multiples of four. The number of circuits in a panel ranges from to 4 to 42, the usual panel size being 18, 30 and 42 circuits. Similar to lighting control panels, they are compatible with BACNet, LonWorks, DMX512, and other common building management communication protocols. They have manual overrides and take the same dry contact signal inputs as lighting control panels. They also can be networked to support a large building or space. The number of panels in a network can go up to 12, with 8 being the average. Some controllable breaker panels can accept mixed loads (120V and 277V). Plug load control can be implemented by upgrade a regular breaker panel to a controllable breaker panel or by increasing the number of controllable breakers in an existing breaker panel if it is already used for general lighting controls.

Figure 4 lists a sample of both types of control panels to demonstrate product availability.

Product Type	**Manufacturer**	**Model**
Lighting Control Panel	Intelligent Lighting Control	Light Master
	Leviton	e EZMax / ZMax
	Lighting Control and Design	GR2400 Quintessence
	Lightholier/Philips	LyteSwitch
	Lutron	LCP128
	Siemens	LCP3000EZ System
	Wattstopper	Lighting Integrator
Controllable Breaker Panel	Cutler Hammer	Power-R-Command
	Lighting Control and design	GR2400 SmartBreaker
	Lutron	XPS
	Schneider Square D	PowerLink
	Siemens	I-3 Control Technology P1 series
	Synergy lighting control	Synergy Controllable Breaker Panel

Figure 4 Examples of Lighting Control and Controllable Breaker Panels

Occupancy Sensor Controls

Occupancy sensor controls have been widely used for general lighting controls. There are no technical barriers to applying this technology to controlled receptacles in the same fashion for general lighting controls.

Per 2008 Title 24 requirements, private offices and conference rooms need to have occupancy sensor controls for overhead lighting. If the overhead lighting is 120V based, the electric circuits can be wired to use one occupancy sensor to control both overhead lighting and controlled receptacle. When the overhead lighting is 270V based, there are three options to accommodate occupancy sensor control of 120V receptacles:

- Add additional high-voltage single-pole occupancy wall switches for the controlled receptacles
- Use a high-voltage 2-pole occupancy sensor, e.g. SensorSwitch WSD-2P-I, with one pole for general lighting and one pole for controlled receptacles. It should be note that most of high-voltage wall occupancy switches are single-pole based.
- Use a low-voltage occupancy sensor, but separate relays, for general lighting and controlled receptacles

The cost analysis considered all these options.

Figure 5 lists manufacturers and models of occupancy sensor controls. For occupancy sensor controls in open-space with cubicles, the occupancy sensor needs to be mounted on cubicle furniture, preferably under the desk. Most of occupancy sensors are designed for wall mount and may not be suitable for cubicle furniture mounting without some packaging modification. Some cubicle furniture manufacturers, e.g. Herman Miller and Haworth, already make furniture that includes occupancy sensor controls. However, they were not used by the CASE study to evaluate cost effectiveness of proposed changes.

Product Type	Manufacturer	Product Name
High-voltage Wall Occupancy Switch	Cooper Controls Greengate	OMC-P-0450-R
	Enerlites	WOSS15-W
	Heath Zenith Lighting	SL-6107-WH
	Leviton	OSC04-I0W
	Lutron	LOS-CIR-450-WH
	SensorSwitch	CM-9, WSD-2P-I (2-Pole)
	Wattstopper	PW100I
Low-voltage Occupancy Sensor with Relay Box	Legrand Wiremold	Convia
	Lutron	Maestro Wireless
	Wattstopper	Room Controller

Figure 5 Examples of Occupancy Sensor Controls

4.3.3 Level of Controls

Occupancy sensor controls have finer granularity of controls than timer controls as they can capture more time periods when controlled plug loads can switched off. It is, therefore, desirable to use occupancy sensors to control controlable plug loads. The CASE study considered three levels of control, with increased use of occupancy sensor controls, to test the maximum level of occupancy sensor controls that can be feasibly and cost-effectively achieved. The three levels of controls are:

- **Level 1**: No occupancy sensor controls. Time switch controls are used for all controlled receptacles.
- **Level 2**: Occupancy sensor controls are used for controlled receptacles in private offices and conference rooms; Time switch controls are used for controlled receptacles in all other spaces including open-space workstations, kitchens, and copy rooms
- **Level 3**: Occupancy sensor controls are used for controlled receptacles located in all building spaces except those in kitchens and copy rooms.

The proposed Level 2 requirements are very similar to 2008 Title 24 shut off control requirements for general lightings. The difference is that the occupancy sensor controls are not applied to kitchens and copy rooms for plug load controls. Certain appliances, such as coffee maker and printers, need to operate without the presence of any occupant. Using occupancy sensor control would lead occupants to plug those appliances into uncontrolled receptacles, which would therefore never be controlled.

4.3.4 Plug Load Circuit Wiring

The proposed plug load controls would require seperate circuits to be connected to controlled and uncontrolled receptacles. This may or may not affect building circuit wiring, depending on the control technologies and existing wiring practices. The CASE study evaluated the impact of industry wiring practices on the measure cost and compliance options.

The number of control channels depends on the number of controlled circuits, which, in turn, are determined by the total power of office task lighting and other controllable plug loads. In general, a 20A circuit can serve plug loads of 2-4 workstations, depending on the expected amount of office equipment installed at each workstation. For cost analysis, the CASE study considered this range of possibility to come up with low and high estimates of control panel upgrade requirements.

Figure 6 illustrates two methods of office electrical system wiring. One is to connect all receptacles is a cubicle to one circuit, and it is referred as single-circuit method. The other is to serve receptacles in a cubicle with at least two circuits, and it is referred as dual-circuit method. Single-circuit wiring is easier to install, but the dual-circuit wiring is more reliable. Most office system furniture (cubicle) on market is configured to take three to four circuit input.

For time switch controls, controlled and uncontrolled circuits need to be separated at the central control panel(s). Hence, dual-circuit wiring is required. According to the industry survey to described in Appendix II: Industry Practice Survey, dual-circuit wiring is the preferred practice for system reliability consideration and represents about 46% of market. All system furniture products accommodate multiple circuit inputs and are equipped with receptacles with coding to differentiate connected circuits. Contractors are required to clearly mark breakers in breaker panels to indicate end connection of each circuit. It requires little additional efforts for electric designers and contractors to separate controlled and uncontrolled circuits/receptacles, connect them to proper control channels, and mark them accordingly. This is especially true when controllable breaker panels are used. If connection mistakes are made, they can be corrected at the control panel.

Upgrading single-circuit wiring design to a dual-circuit wiring only have minor impact on wiring cost. A close examination of the two wiring methods shown in Figure 6 reveals that the total wiring length difference between the two methods is small. This difference is included in the cost analysis.

New construction office buildings may be finished without installation of workstation furniture, which will be added later as part of the tenant improvement (TI) project, possibly along with installation/improvement of overhead lightings. In this case, circuits for workstations will not be connected to any receptacles. For the Title 24 compliance consideration, the proposed code change would require that all unconnected circuits have to be marked to differentiate controlled circuits from uncontrolled one to allow inspection and proper future installation. Local building department may impose inspection during and after TI projects and installation of controlled receptacles can be inspected accordingly.

Occupancy sensor controls are installed locally. An electric circuit can be split into two branches locally with one branch been controlled by the occupancy sensor for controllable receptacles, while the other branch serves uncontrolled receptacles. More often, multiple circuits are supplied to a workstation or other office spaces. In this case, one or two circuits can be wired to an occupancy sensor to serve controllable recetacles.

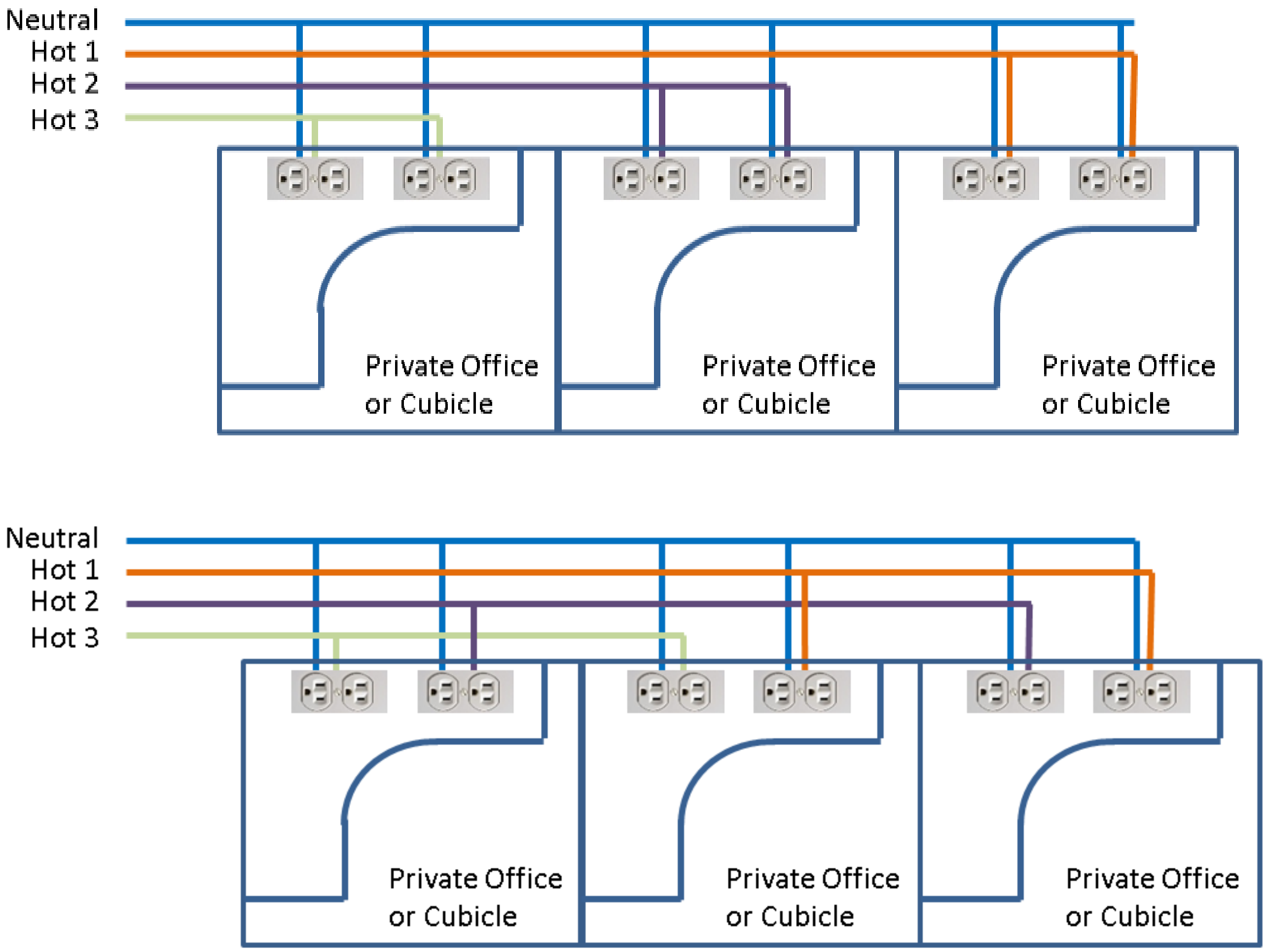


Figure 6 Single circuit (top) versus double circuit (bottom) wiring practice

4.4 Prototype Buildings Development

The CASE study developed small and large office building prototypes based on information provided in DEER. The detailed space layouts are provided in Appendix III: Office Building Prototypes.

The DEER small office building prototype has two stories, with a rectangular footprint (50ft×100ft) and total floor area of 10,000 sf. The building was estimated to have thirty three (33) occupants with nine (9) private offices and one conference room on each floor.

The DEER large office building prototype has ten stories, 175,000 sf building, with a rectangular footprint (175ft×100ft) and total floor area of 175,000 sf. It was estimated there were seven hundred and thirty (730) occupants working in this building. All floors have a similar layout, which includes 19 private offices, 54 cubicles, 2 conference rooms, 2 copy rooms, kitchen and restrooms.

	Type	Area (Square Feet)	Number of Stories
Prototype 1	Small Office	10,000	2
Prototype 2	Large Office	175,000	10

Figure 7 Office Building Prototype Summary

4.5 Energy Savings Analysis

Energy savings for the three levels of plug load control are estimated for both office building prototypes. The following sections provide detailed description of assumptions, calculation steps, and tool used for energy savings calculation.

4.5.1 Energy Savings Analysis Assumptions

Controllable Plug Load Density

Controllable plug loads definition and installation density were discussed in details in 4.1 Plug Load Characteristics Study. The results are presented in Figure 2 and Figure 3, respectively.

Control Periods

Office business hours are based on general office working schedules. For private office and open-space cubicle, the CASE team considered average away-from-desk time for events such as lunch break, meetings, early leave, etc., and out-of-office time for events such as vacation, sick leave, business travels, work at home, jury duty, and other personal leaves. For conference room occupancy, assumptions were made on the average unoccupied hours during business hours. Figure 8 provides annual hours of each control period, along with all assumptions of office operation schedules and occupant working schedules used to develop the control periods.

Plug Load Power Status

The LBNL Study and ECOS Study are the only data sources that provide comprehensive usage statistics of different plug loads. The LBNL Study measured nighttime operation status of computer and office printing equipment. The ECOS Study provided averaged daily usage statistics for all plug loads. Based on the two studies, the CASE team further developed power state statistics for each controllable plug load during different control periods. The results are shown in Figure 9, Figure 10 and Figure 11. The percentages in these figures represent the percent of total plug load devices of a specific type that at a corresponding power state. Plug load power state statistics during out-of-office hours was assumed to be same as those during non-business hours. For example, in Figure 9 it is that 5% of all table lamps are in active mode (turned on) during non-business hours or out-of-office hours. In Figure 10 it is assumed that 33% of table lamps are left on when occupants are away from their desks.

Annual Office Hours	
Number of weekend days	104
Number of holiday	10
Number of business days	251
Average business hours/day	12
Business hours	3012
Annual Private Office/Work Station Hours	
Number of vacation days	15
Number of sick/personal leave days	8
Number of business travel/work-at-home days	5
Annual in-office days	223
Average hour in office per day	9
Average lunch/break hours/day	1
Average away-from-desk meeting hours/day	1
Annual OC controlled hours	1451
Annual Conference Room Hours	
Average occupied hours per day	5
Annual un-occupied hours during business hours	1757
Control Period Summary	
Non-business Hours (Timer control hours)	5748
Annual out-of-office hours	336
Annual away-from-desk hours	1115
Annual un-occupied hours during business hours	1757

Figure 8 Office Operation and Occupant Working Schedule Assumptions

For each controllable plug load type *i* (e.g. task lights, PC monitor, etc.), the energy savings during a control period *j* equal to the total energy consumption by this type of plug load when it is switched off by the control. They are calculated as following:

$$Energy\ Savings_{i,j} = \sum_{PS} Number\_of\_Plug\_Load_i \times PS\_Percent_{i,PS,j} \times Power_{i,PS,j}$$

PS = {Active, idle, sleep, standby}

The number of plug load for type *i* in a building is its installation density multiplied by building size. Values for $Power_{i,PS,j}$ are listed in Figure 3 and values for $PS\_Percent_{i,PS,j}$ are provided in Figure 9, Figure 10, and Figure 11. Average plug load power status depends on control period. For example, average table lamp power consumption during non-business hours is expected to be lower than that during business hours when occupants are away from desks.

The above calculation was performed for each controllable plug load type and control period. Then, hourly energy savings were estimated based on office operation schedule provided in Figure 8. During non-business hours, energy savings are achieved for every hour. For energy savings achieved by occupancy sensor controls during the three business-hour control periods, we assumed that the hours of control period provided in Figure 8 are evenly distributed among the range of business hours, with the exception that lunch hours were assumed to only from 12pm to 1pm.

For both time switch control and occupancy sensor controls, personal fans and heaters were assumed to be used in summer and winter months, respectively.

Timer controls will only capture savings during the non-business hour control period, while occupancy sensor controls are will be able to capture energy savings during all control periods.

Plug Load	**Active**	**Idle**	**Sleep**	**Standby**	**Disconnect**
Task Lighting					
Lamp, Desk attachment	5%	0%	0%	5%	90%
Lamp, Table	5%	0%	0%	2%	93%
Monitor					
CRT	10%	15%	0%	35%	40%
LCD	10%	15%	0%	35%	40%
Printing/Imaging Equipment					
Laser MFD	0%	28%	0%	45%	27%
Inkjet MFD	0%	28%	0%	70%	2%
Laser printer	0%	35%	0%	45%	20%
Inkjet printer	0%	0%	0%	60%	40%
Wide Format Printer	0%	0%	0%	75%	25%
Document Scanner	0%	0%	0%	95%	5%
Audio /video					
Television, LCD	0%	0%	0%	34%	66%
DVD player	0%	0%	0%	100%	0%
Video Projector	0%	0%	5%	64%	31%
Speakers	0%	37%	2%	40%	21%
Subwoofer	0%	100%	0%	0%	0%
CD Player	0%	0%	0%	95%	5%
Computer Speakers	0%	90%	0%	4%	6%
Portable Stereo	0%	5%	0%	86%	9%
Portable CD player	0%	8%	0%	75%	17%
Table Radio	0%	0%	0%	84%	16%
Other					
Adding machine	0%	40%	0%	37%	23%
Shredder	0%	0%	0%	60%	40%
Stapler	0%	48%	0%	50%	2%
Typewriter, Electric	0%	44%	0%	50%	6%
Fan, portable	0%	0%	0%	80%	20%
Space heater, portable	0%	0%	0%	99%	1%

Kitchen Appliance					
Coffee Grinder	0%	45%	0%	25%	30%
Coffee Maker	0%	0%	0%	80%	20%
Toaster oven	0%	0%	0%	33%	67%
Microwave oven	0%	0%	0%	100%	0%
Water dispenser	5%	0%	0%	95%	0%
Vending machine	0%	0%	0%	100%	0%
Hot beverage dispenser	0%	0%	0%	100%	0%

Figure 9 Plug Load Power State Statistics –Non-Business Hours

Plug Load	**Active**	**Idle**	**Sleep**	**Standby**	**Disconnect**
Task Lighting					
Lamp, Desk attachment	49%	0%		20%	32%
Lamp, Table	33%	0%		14%	55%
Monitor					
CRT	55%	15%	15%	15%	0%
LCD	55%	15%	15%	15%	0%
Audio /video					
Computer Speakers	4%	87%	0%	4%	5%
Portable Stereo	9%	22%		86%	
Portable CD player	15%	11%		75%	0%
Table Radio	47%			84%	
Other					
Fan, portable	3%			80%	17%
Space heater, portable	3%			99%	

Figure 10 Plug Load Power State Statistics –Away-from-desk

Plug Load	Active	Idle	Sleep	Standby	Disconnect
Audio /video					
Television, LCD	47%			34%	19%
DVD player				100%	
Video Projector	17%		5%	64%	14%
Speakers	20%	37%	2%	40%	1%
Subwoofer		100%			
CD Player	15%			95%	

Figure 11 Plug Load Power State Statistics – Empty Conference Room

4.5.2 Energy Savings Analysis Results

An EXCEL spreadsheet was developed to performance energy savings analysis based on the algorithms described above. Figure 12 shows the annual energy savings on per building and per square foot basis. Figure 13 provides percentage breakdown of savings into different plug load categories. It is clear that most of the savings are from controlling task lights and computer monitors. Figure 14 and Figure 15 present life cycle TDV savings benefits and annual TDV energy savings per square foot of building areas, respectively for each level of controls, as defined in section 4.3.3. Savings variation among sixteen (16) climate zones is due TDV value differences. For further cost-effectiveness analysis, averaged savings of all sixteen (16) climate zones were used.

	Small Office			Large Office		
	Level 1	**Level 2**	**Level 3**	**Level 1**	**Level 2**	**Level 3**
	Annual Electric Energy Savings (kW/year)					
Per building	4197	4912	5486	97844	106751	128818
Per SQFT	0.42	0.49	0.55	0.56	0.61	0.74
	Annual peak demand savings (kW/year)					
Per building	0	1.97	3.56	0	23.6	83.9
Per SQFT	0	0.000197	0.000356	0	0.000135	0.000480

Figure 12 Annual Energy Savings from Three Levels of Controls

	Small Office			**Large Office**		
	Level 1	**Level 2**	**Level 3**	**Level 1**	**Level 2**	**Level 3**
Task Lighting	13%	16%	17%	12%	12%	10%
Monitor	50%	51%	52%	51%	47%	39%
Imaging	18%	16%	14%	17%	16%	13%
Audio /video	12%	12%	12%	13%	12%	10%
Other	2%	2%	2%	3%	2%	2%
Kitchen Appliance	4%	4%	3%	4%	3%	3%
Total	100%	100%	100%	100%	100%	100%

Figure 13 Breakdown of Plug Load Control Savings

	Small Office			**Large Office**		
Climate Zone	**Level 1**	**Level 2**	**Level 3**	**Level 1**	**Level 2**	**Level 3**
1	$0.69	$0.85	$0.98	$0.92	$1.04	$1.32
2	$0.70	$0.85	$0.97	$0.94	$1.04	$1.30
3	$0.72	$0.86	$0.98	$0.96	$1.06	$1.31
4	$0.76	$0.89	$1.00	$1.02	$1.11	$1.34
5	$0.79	$0.91	$1.01	$1.05	$1.14	$1.36
6	$0.80	$0.92	$1.02	$1.07	$1.16	$1.36
7	$0.85	$0.96	$1.05	$1.13	$1.21	$1.41
8	$0.85	$0.96	$1.04	$1.14	$1.21	$1.40
9	$0.86	$0.96	$1.04	$1.15	$1.22	$1.40
10	$0.86	$0.96	$1.04	$1.15	$1.22	$1.39
11	$0.87	$0.97	$1.05	$1.16	$1.23	$1.41
12	$0.86	$0.97	$1.05	$1.15	$1.22	$1.40
13	$0.85	$0.96	$1.04	$1.13	$1.21	$1.40
14	$0.83	$0.94	$1.03	$1.10	$1.18	$1.38
15	$0.80	$0.92	$1.01	$1.06	$1.15	$1.36
16	$0.77	$0.90	$1.00	$1.03	$1.12	$1.34

Figure 14 Present Values of Life Cycle Energy Savings ($/sf)

	Small Office			Large Office		
Climate Zone	**Level 1**	**Level 2**	**Level 3**	**Level 1**	**Level 2**	**Level 3**
1	7.96	9.67	11.03	10.61	11.82	14.81
2	8.18	9.73	10.97	10.90	12.00	14.72
3	8.46	9.95	11.14	11.26	12.33	14.95
4	8.93	10.31	11.41	11.89	12.88	15.30
5	9.16	10.48	11.55	12.20	13.14	15.48
6	9.33	10.58	11.58	12.42	13.31	15.52
7	9.73	10.94	11.91	12.95	13.82	15.96
8	9.71	10.84	11.75	12.93	13.74	15.74
9	9.73	10.83	11.71	12.95	13.74	15.68
10	9.70	10.81	11.69	12.91	13.71	15.66
11	9.69	10.85	11.78	12.90	13.73	15.78
12	9.55	10.76	11.73	12.72	13.58	15.71
13	9.35	10.61	11.63	12.45	13.35	15.58
14	8.99	10.32	11.40	11.97	12.92	15.27
15	8.64	10.07	11.22	11.50	12.53	15.05
16	8.28	9.83	11.08	11.03	12.13	14.87

Figure 15 Annual TDV Energy Savings (kBtu/sf/yr)

4.6 Cost Analysis

The proposed code changes involve two types of control strategies, time switch control and occupancy sensor control. The three levels of control defined in section 4.3.3 build on different combinations of the two control technologies. In order to estimate the incremental cost of the three levels of controls, control system improvement options were developed for different baseline lighting control and electric panel systems. Design parameters for each improvement option were provided for cost analysis and for demonstrating compliance options. The incremental costs were calculated as the cost difference between the improved control systems and the corresponding baseline system.

4.6.1 Control System Baselines and Compliance Options

This section describes the general design requirements (baseline) and improvement options (compliance options) specific to time switch controls and occupancy sensor controls. The next section describes how these options are combined to achieve the three levels of system controls. System incremental costs were estimated accordingly.

Time Switch Control

For time switch control, the baseline overhead lighting controls per 2008 Title 24 requirements was developed assuming the common practice of using either central lighting control panels or central controllable breaker panels to control general lighting. The CASE team considered four baseline designs based on the use of either controllable breaker panels or lighting control panels, and overhead lighting voltage (277V or 120V). When 277V overhead lighting fixtures are used, separate breaker panels are usually needed to serve the two sets of circuits for overhead lighting and plug loads. The following diagrams and tables present the four baseline designs and their corresponding upgrade options for plug load control.

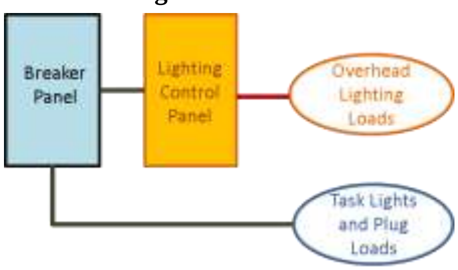
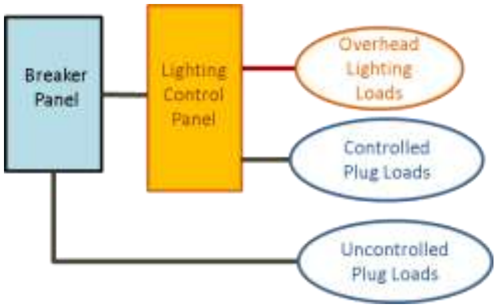
Design A	**Breaker Panel**	**Lighting Control Panel**
Baseline Design 	A single 120V breaker panel for both general lighting and plug loads.	A lighting control panel for general lighting (120V)
Plug Load Control Option 	No Change	Increase number of control channels in the lighting control panel(s) to accommodate controlled plug load circuits; potentially a large panel is needed.

Figure 16 Time Switch Control Baseline and Plug Load Control Option – Design A

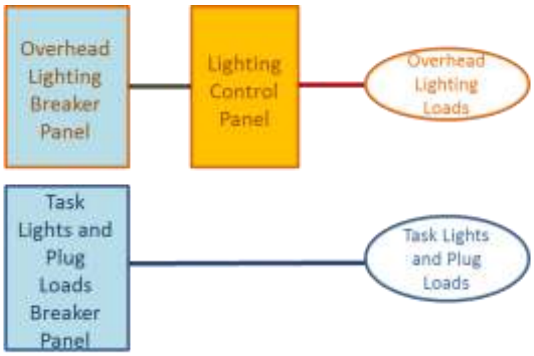
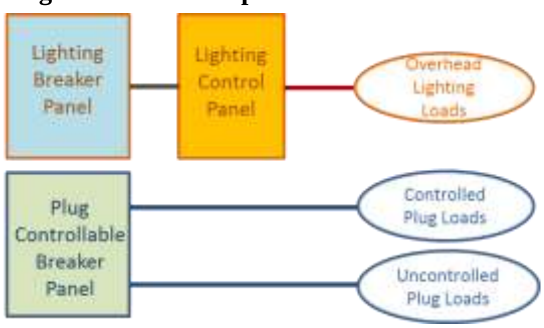
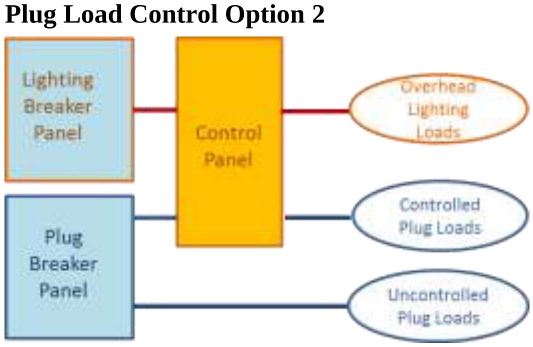
Design B	Breaker Panel	Lighting Control Panel
Baseline Design 	Separate breaker panels for general lighting and plug loads; general lighting could be 120V or 277V based.	General lighting (120V or 277V) are controlled by lighting control panel(s).
Plug Load Control Option 1 	Upgrade the regular breakers to a controllable breaker panel; only control circuits serving controlled receptacles are controlled.	No change
Plug Load Control Option 2 	No change	Increase number of control channels to accommodate controlled plug load circuits. potentially a large panel is needed. A voltage barrier is needed if general light and plug loads have different voltages.

Figure 17 Time Switch Control Baseline and Plug Load Control Option – Design B

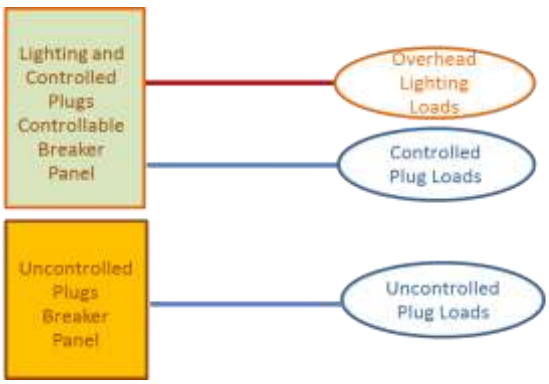
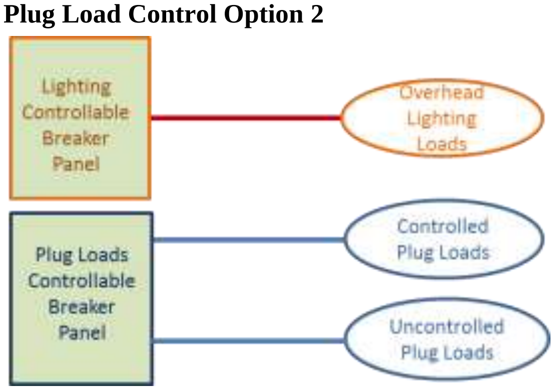
Design C	**Breaker Panel**	**Lighting Control Panel**
Baseline Design 	Separate breaker panels for general lighting and plug loads; the breaker panel for general lighting is controllable, 120V or 277V.	None
Plug Load Control Option 1 	Use a larger controller breaker panel for both general lighting and plug load.	No change
Plug Load Control Option 2 	Upgrade the break panel(s) for plug loads to controllable breaker panel(s).	No change

Figure 18 Time Switch Control Baseline and Plug Load Control Option – Design C

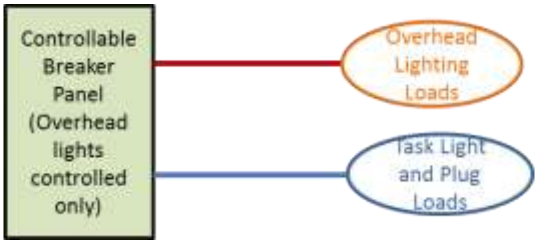
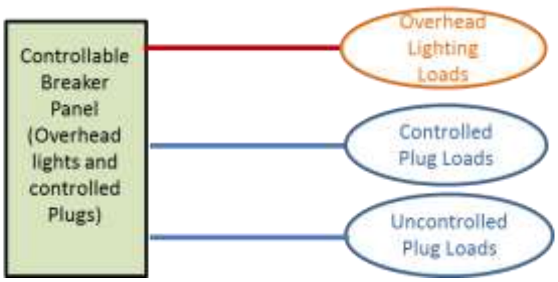
Design D	**Breaker Panel**	**Lighting Control Panel**
Baseline Design 	Same controllable breaker panel(s) for both general lighting and plug loads; only general lighting circuits are controlled	None
Plug Load Control Option 	Increase the number of controlled circuit channels for plug load control.	No change

Figure 19 Time Switch Control Baseline and Plug Load Control Option – Design D

Industry practice survey indicated that the dual circuit wiring design, which brings at least two independent circuits into workstations, represents 46% of the market practice. Hence, the baseline is a weighted average of dual-circuit wiring and single-circuit wiring. The cost for upgrading to a dual-circuit design was estimated for the two office building prototypes based on the method described in section 4.3.4.

Occupancy Sensor Control

The 2008 Title 24 requires that office spaces less than 250 sf should be equipped with occupancy sensor for general lighting shut-off controls. This requirement effectively covers most private offices and conference rooms. This requirement is used as the baseline for evaluating incremental costs of occupancy sensor controls for plug load, which could be achieved with the following system upgrade options:

- When a **high**-voltage occupancy sensor switch is used for general lighting control:
  - If the general lighting is 120V based, the same occupancy sensor switch can be wired for both general lighting and plug load controls
  - If the general lighting is 277V based, another occupancy sensor switch (120V) needs to be installed for plug load control, or a 2-pole occupancy sensor switch can be installed to support the 277V general lighting circuit and the 120V plug load circuit.
- When a **low**-voltage occupancy sensor is used for general lighting control, the corresponding lighting control or relay box needs to be upgraded to include an additional channel to support plug load control.

For the first scenario, we consider the high-cost option, which uses two occupancy sensor switches, to make the cost effectiveness analysis conservative. The two scenarios of using high-voltage and low voltage occupancy sensors are illustrated in Figure 20.

For open-space workstations, there is no baseline control requirement. The proposed changes, as in the level 3 control, can be met by installing a high-voltage occupancy sensor located in each workstation.

Occupancy sensor controls do not require dual-circuit wiring from breaker panels. The incoming circuit can be split locally to support both controlled and uncontrolled receptacles.

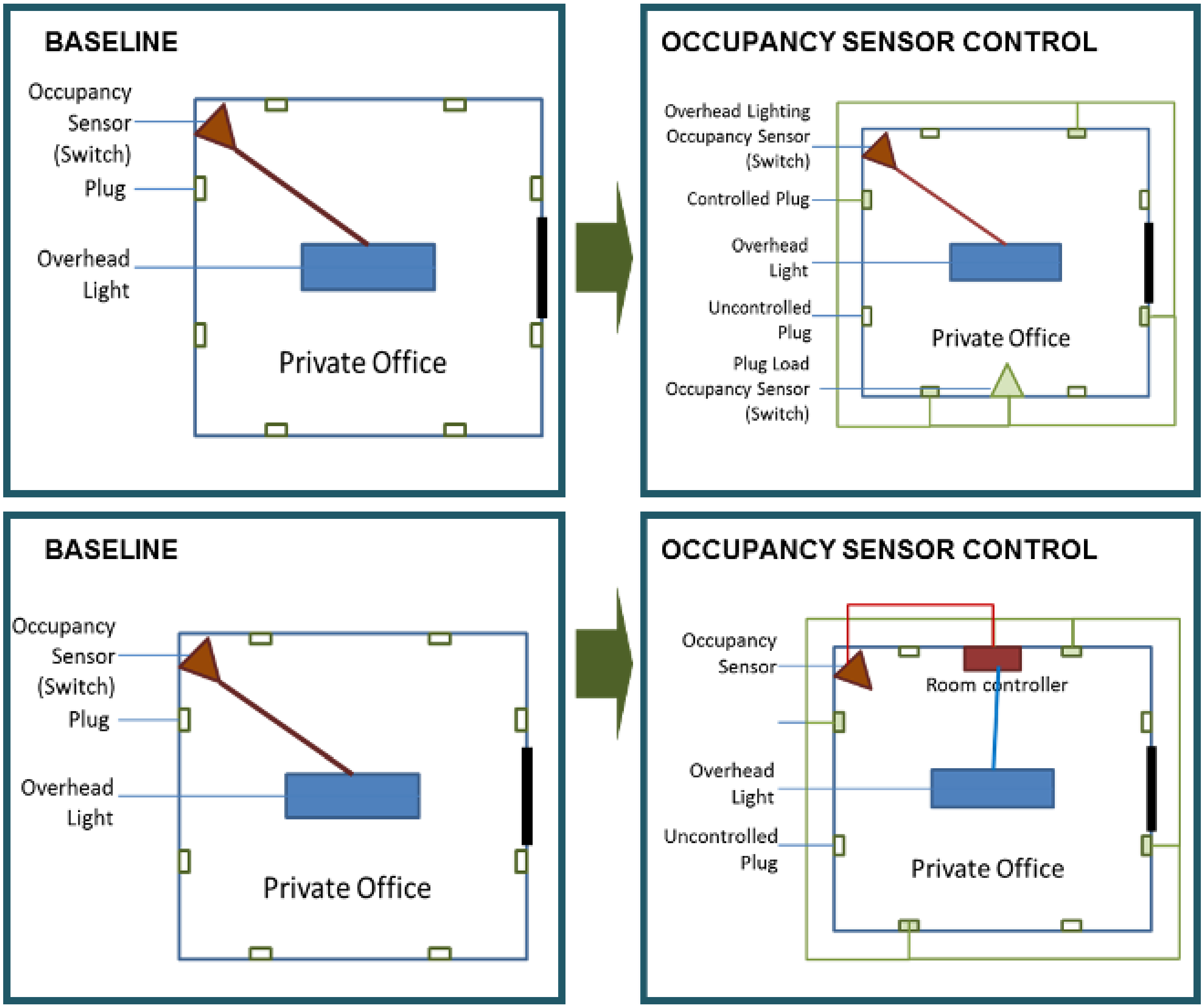


Figure 20 Occupancy Sensor Control Baselines and Plug Load Control Options (top: high-voltage; bottom: low-voltage)

4.6.2 Incremental Cost of Three Levels of Controls

The section provides detailed incremental cost estimation for the three levels of plug load controls, as described in section 4.3.3.

First, the general electric systems for both the small and large office building prototypes were assessed. The small office was assumed to have a central location for breaker panel(s) and lighting control panel(s) on each floor, with the first floor hosting the master panel, which includes the controller logics. The large office building needed to have two control panel locations on each floor, because the maximum wiring length needed to be less than 120-ft to prevent excessive voltage drop. Two master control panels were used to serve two control-panel networks, one for each side of the building so network wiring can be easily routed along vertical electrical shafts.

Second, the total number of circuits for general lighting and plug loads were determined based on office space configurations. This information was used to determine control panel sizes. The number of general lighting circuits was determined based on a lighting power density of 0.9 W/sf. The number of 120 V plug load circuits was estimated based on the office layout as well as on electric system design practices. The analysis considered two levels of assumption of number of circuits used to serve each space type, as shown in Figure 21, to cover the range of possible wring practices. A 20% extra capacity was used for panel sizing to accommodate for future expansion, as commonly done.

Load Type	**Space Type**	**More Circuits**	**Less Circuits**
Plug Loads	Private Office	1 circuit/private office	1/2 circuit/private office
	Open Space Cubicle	½ circuit/cubicle	¼ circuit/cubicle
	Copy Room	1 circuit/copy room	
	Lobby, Corridor	1 circuit	
	Kitchen	2 circuits/kitchen	
	Mechanical Room	2 circuits/mechanical room	
General Lighting	Overhead lighting	0.9 W/sf LPD, 3 amp/circuit	0.9 W/sf LPD, 4 amp/circuit

Figure 21 Number of Circuits per Space Type

Third, the total incremental costs were estimated based on system upgrade requirements as described in the prior section for each baseline design case. Figure 22 provides costs of central control panels for several standard sizes, obtained from manufacturer surveys. Master panels include control logics while slave panels can only receive control signals. In scenarios where standard circuit breaker panels are replaced with controllable breaker panels, such as for design scenario B and C, the incremental cost of controllable breaker panels is used as system upgrade cost. Costs of standard breaker panels were estimated to be $25 per circuit channel based on market surveys. The cost for control panel installation and configuration is assumed to be 2 hr per control panel. Wiring material and labor costs were assessed using RS Means data as 1.27 hr/ 100ft of wire. Electric contractor hourly labor rate was assumed to be 86.11 /hr. Figure 23 provides cost estimate for each occupancy sensor option.

Panel Type	**Type**	**8 relays /breakers**	**24 relays /breakers**	**42 relays /breakers**
Lighting Control Panel	**Master**	$2,305	$3,085	$3,960
	Slave	$1,495	$2,305	$3,215
Controllable Breaker Panel	**Master**	$1,090	$2765	$4,650
	Slave	$930	$2,335	$3,915

Figure 22 Cost of Central Control Panels

Options	**Unit Price**	**Installation Time/unit**	**Labor Cost /unit**
One High-voltage Wall Switch	$25	0.35	$ 30
One additional Relay Channel for Low-voltage Occupancy Sensor Control	$100	0.7	$ 60

Figure 23 Cost of Occupancy Sensor Controls

Level 1 Control Incremental Cost

This level of control requires all plug loads to be controlled by time switch controls. System upgrade options to meet the control requirement are summarized in Figure 24. Additional wiring length to support dual-circuit wiring is shown in Figure 25. Unit incremental costs per building floor area are summarized in Figure 26. For a baseline electric system design using minimum number of circuits (Less Circuits), more wiring upgrade is required to support controllable receptacles than the baseline design using more circuits (More Circuits). Total incremental cost also depends on incremental cost associated with control panel upgrade options. As shown in Figure 26, some scenarios of “Less Circuits” show slightly higher incremental cost than corresponding “More Circuits” scenarios.

Baseline	Option	Small Office		Large Office	
		Less Circuits	**More Circuits**	**Less Circuits**	**More Circuits**
A	**1**	Add 6 relays in each control panel	Add 8 relays in each control panel	Add 9 relays in each control panel	Add to 15 relays in each control panel
B	**1**	Change task/plug loads breaker panel by controllable breaker panel			
	2	Add 6 relays in each control panel	Add 8 relays in each control panel	Add 9 relays in each control panel	Add 15 relays in each control panel
C	**1**	For each controllable breaker panel, add 6 controlled and 14 uncontrolled breakers, eliminate non-controllable breaker panels	For each controllable breaker panel, add 8 controlled and 16uncontrolled breakers, eliminate non-controllable breaker panels	For each controllable breaker panel, add 9 controlled and 16 uncontrolled breakers, eliminate non-controllable breaker panels	For each controllable breaker panel, add 15 controlled and 23 uncontrolled breakers, eliminate non-controllable breaker panels
	2	Change task/plug loads breaker panel by controllable breaker panel			
D	**1**	Replace 6 regular breakers with controllable breakers in each controllable breaker panel	Replace 8 regular breakers with controllable breakers in each controllable breaker panel	Replace 9 regular breakers with controllable breakers in each controllable breaker panel	Replace 15 regular breakers with controllable breakers in each controllable breaker panel

Figure 24 Control System Upgrade Requirement – Level 1 Control

	Small Office		Large Office	
	Less Circuits	**More Circuits**	**Less Circuits**	**More Circuits**
Additional Wiring Length (ft)	252	120	3,250	2,340

Figure 25 Additional Wiring Length for Dual-Circuit Wiring – Level 1 Control

Baseline	Time Switch Control Option	Small Office		Large Office	
		Less Circuits	**More Circuits**	**Less Circuits**	**More Circuits**
A	1	$0.25	$0.26	$0.17	$0.23
B	1	$0.55	$0.55	$0.29	$0.33
	2	$0.29	$0.29	$0.18	$0.25
C	1	$0.18	$0.17	$0.12	$0.15
	2	$0.52	$0.51	$0.27	$0.31
D	1	$0.17	$0.14	$0.11	$0.14

Figure 26 System Incremental Cost – Level 1 Control ($/sf)

Level 2 Control Incremental Cost

In this control level, time switch control is used for plug loads serving open-space workstations, kitchens, and copy rooms and occupancy sensor controls are used in private offices and conference rooms. Central control panel upgrade requirements are summarized in Figure 27. Level 2 control requires less additional wiring since occupancy sensors are used in private offices, which do not require dual circuits. Figure 29 shows the unit are system upgrade incremental cost for each prototype. Similar to the level 1 control, when an office electric system has relatively less number of circuits, more system upgrade might be needed, therefore having a higher incremental cost.

Baseline	Option	Small Office		Large Office	
		Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	Add 1 relay in each control panel	Add 3 relays in each control panel	Add 5 relays in each control panel	Add 9 relays in each control panel
B	1	Change task/plug loads breaker panel by controllable breaker panel			
	2	Add 1 relay in each control panel	Add 3 relays in each control panel	Add 5 relays in each control panel	Add 9 relays in each control panel
C	1	For each controllable breaker panel, add 1 controlled and 17 uncontrolled breakers, eliminate non-controllable breaker panels	For each controllable breaker panel, add 3 controlled and 23 uncontrolled breakers, eliminate non-controllable breaker panels	For each controllable breaker panel, add 5 controlled and 21 uncontrolled breakers, eliminate non-controllable breaker panels	For each controllable breaker panel, add 9 controlled and 29 uncontrolled breakers, eliminate non-controllable breaker panels
	2	Change task/plug loads breaker panel by controllable breaker panel			
D	1	Replace 2 regular breakers with controllable breakers in each controllable breaker panel	Replace 3 regular breakers with controllable breakers in each controllable breaker panel	Replace 8 regular breakers with controllable breakers in each controllable breaker panel	Replace 9 regular breakers with controllable breakers in each controllable breaker panel

Figure 27 Control System Upgrade Requirement – Level 2 Control

	Small Office		Large Office	
	Less Circuits	More Circuits	Less Circuits	More Circuits
Additional Wiring Length (ft)	100	50	1,500	1,000

Figure 28 Additional Wiring Length for Dual Circuit Wiring Support– Level 2 Control

Baseline	Time Switch Control Option	Occupancy Sensor Control Option	Small Office		Large Office	
			Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	Low-voltage	$0.27	$0.26	$0.18	$0.23
		High-voltage	$0.42	$0.41	$0.27	$0.32
B	1	Low-voltage	$0.64	$0.65	$0.34	$0.37
		High-voltage	$0.79	$0.80	$0.43	$0.46
	2	Low-voltage	$0.30	$0.30	$0.20	$0.24
		High-voltage	$0.45	$0.45	$0.29	$0.29
C	1	Low-voltage	$0.28	$0.28	$0.17	$0.20
		High-voltage	$0.43	$0.43	$0.26	$0.29
	2	Low-voltage	$0.61	$0.61	$0.32	$0.37
		High-voltage	$0.76	$0.76	$0.41	$0.46
D	1	Low-voltage	$0.22	$0.20	$0.13	$0.17
		High-voltage	$0.37	$0.35	$0.22	$0.26

Figure 29 System Incremental Cost – Level 2 Control ($/sf)

Level 3 Control Incremental Cost

The level 3 control requires occupancy sensor controls to be installed in private offices, open-space cubicles, and conference rooms and time switch control is applied to controllable plug loads in kitchens and copy rooms. Figure 30 shows the number of occupancy sensor controls needed for each prototype building. It is assumed that open-space cubicles will use high-voltage switch type of occupancy sensor. Figure 32 shows the system upgrade incremental costs per square foot for each prototype.

Baseline	**Time Switch Control Option**	**Occupancy Sensor Control Option**	**Small Office**		**Large Office**	
			Less Circuits	**More Circuits**	**Less Circuits**	**More Circuits**
A	1	Low-voltage	$0.25	$0.27	$0.28	$0.29
		High-voltage	$0.40	$0.42	$0.37	$0.38
B	1	Low-voltage	$0.65	$0.67	$0.48	$0.50
		High-voltage	$0.80	$0.82	$0.57	$0.59
	2	Low-voltage	$0.27	$0.29	$0.29	$0.30
		High-voltage	$0.42	$0.44	$0.38	$0.45
C	1	Low-voltage	$0.30	$0.33	$0.32	$0.36
		High-voltage	$0.45	$0.48	$0.41	$0.45
	2	Low-voltage	$0.63	$0.66	$0.47	$0.51
		High-voltage	$0.78	$0.81	$0.56	$0.60
D	1	Low-voltage	$0.22	$0.25	$0.26	$0.27
		High-voltage	$0.37	$0.40	$0.35	$0.36

Figure 30 System Incremental Cost – Level 3 Control ($/sf)

	Small Office		**Large Office**	
	High-voltage OC sensor in Private Office & Conference room	Low-voltage OC sensor in Private Office & Conference room	High-voltage OC sensor in Private Office & Conference room	Low-voltage OC sensor in Private Office & Conference room
Number of High-voltage Wall Switch	33	13	750	540
Number of Low-voltage Occupancy Sensor	0	20	0	210

Figure 31 Number of Occupancy Sensors Needed for Level 3 Control

Baseline	Time Switch Control Option	Occupancy Sensor Control Option	Small Office		Large Office	
			Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	Low-voltage	$0.25	$0.27	$0.28	$0.29
		High-voltage	$0.40	$0.42	$0.37	$0.38
B	1	Low-voltage	$0.65	$0.67	$0.48	$0.50
		High-voltage	$0.80	$0.82	$0.57	$0.59
	2	Low-voltage	$0.27	$0.29	$0.29	$0.30
		High-voltage	$0.42	$0.44	$0.38	$0.45
C	1	Low-voltage	$0.30	$0.33	$0.32	$0.36
		High-voltage	$0.45	$0.48	$0.41	$0.45
	2	Low-voltage	$0.63	$0.66	$0.47	$0.51
		High-voltage	$0.78	$0.81	$0.56	$0.60
D	1	Low-voltage	$0.22	$0.25	$0.26	$0.27
		High-voltage	$0.37	$0.40	$0.35	$0.36

Figure 32 System Incremental Cost – Level 3 Control ($/sf)

4.7 Cost Effectiveness Analysis

Results of energy savings and cost analysis were combined to produce LCC as defined in section 3.5. The results are shown in Figure 33, Figure 34 and Figure 35 for the three levels of control, respectively. As energy savings variation among different climate zones are small, averaged TDV energy savings among all sixteen (16) climate zones were used to evaluate measure cost effectiveness. The results clearly indicate all three levels of proposed controls have negative LCC values, therefore, they are cost effective.

Baseline	Time Switch Control Option	Small Office		Large Office	
		Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	($0.58)	($0.57)	($0.92)	($0.86)
B	1	($0.28)	($0.28)	($0.80)	($0.76)
	2	($0.54)	($0.54)	($0.91)	($0.84)
C	1	($0.65)	($0.66)	($0.97)	($0.94)
	2	($0.31)	($0.32)	($0.82)	($0.78)
D	1	($0.66)	($0.69)	($0.98)	($0.95)

Figure 33 LCC – Level 1 Control

Baseline	Time Switch Control Option	Occupancy Sensor Control Option	Small Office		Large Office	
			Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	Low-voltage	($0.67)	($0.68)	($0.99)	($0.94)
		High-voltage	($0.52)	($0.53)	($0.90)	($0.85)
B	1	Low-voltage	($0.30)	($0.29)	($0.83)	($0.80)
		High-voltage	($0.15)	($0.14)	($0.74)	($0.71)
	2	Low-voltage	($0.64)	($0.64)	($0.97)	($0.93)
		High-voltage	($0.49)	($0.49)	($0.88)	($0.88)
C	1	Low-voltage	($0.66)	($0.66)	($1.00)	($0.97)
		High-voltage	($0.51)	($0.51)	($0.91)	($0.88)
	2	Low-voltage	($0.33)	($0.33)	($0.85)	($0.80)
		High-voltage	($0.18)	($0.18)	($0.76)	($0.71)
D	1	Low-voltage	($0.72)	($0.74)	($1.04)	($1.00)
		High-voltage	($0.57)	($0.59)	($0.95)	($0.91)

Figure 34 LCC – Level 2 Control

Baseline	Time Switch Control Option	Occupancy Sensor Control Option	Small Office		Large Office	
			Less Circuits	More Circuits	Less Circuits	More Circuits
A	1	Low-voltage	($0.78)	($0.76)	($1.09)	($1.08)
		High-voltage	($0.63)	($0.61)	($1.00)	($0.99)
B	1	Low-voltage	($0.38)	($0.36)	($0.89)	($0.87)
		High-voltage	($0.23)	($0.21)	($0.80)	($0.78)
	2	Low-voltage	($0.76)	($0.74)	($1.08)	($1.07)
		High-voltage	($0.61)	($0.59)	($0.99)	($0.92)
C	1	Low-voltage	($0.73)	($0.70)	($1.05)	($1.01)
		High-voltage	($0.58)	($0.55)	($0.96)	($0.92)
	2	Low-voltage	($0.40)	($0.37)	($0.90)	($0.86)
		High-voltage	($0.25)	($0.22)	($0.81)	($0.77)
D	1	Low-voltage	($0.81)	($0.78)	($1.11)	($1.10)
		High-voltage	($0.66)	($0.63)	($1.02)	($1.01)

Figure 35 LCC – Level 3 Control

4.8 Statewide Energy Savings

Statewide energy savings were estimated by multiplying unit energy savings by the statewide new construction floor areas that are covered by the proposed code change. In the next section, we recommend that the level 2 control be adopted as the mandatory plug load controls requirement. Accordingly, the following statewide energy savings estimate is based on energy savings from the level 2 control.

Energy savings analysis in the prior section provided unit energy savings for both small and large office buildings. However, it might take some time for building operators and occupants to get familiar with plug load controls and to feel comfortable to connect all controllable plug loads to controlled receptacles. The CASE study considers the energy savings reduction due to this acceptance issue. We expect that controls of task lights and computer monitors are more acceptable, because, in general, people are used to task lights being turned on and off and computer monitors need to be wake up from standby or sleeping modes. We are uncertain about people's behavior on shut off controls of copy machines and kitchen appliances. Plug load control implementation rates were estimated for each plug load category according to this logic and are shown in Figure 36. Combined with the energy savings breakdown for each plug load category shown in Figure 13, weight average of overall implementation rates for small and large offices were calculated. The results are shown in Figure 37. Unit energy savings estimated in section 4.5.2 were discounted by these implementation rates as a way to reflect energy savings reduction. The discounted unit energy savings are shown in Figure 37.

Statewide new construction building floor areas in 2014 were obtained from CEC forecast. For each of the following non-office nonresidential buildings, we assumed that certain percentages of the total floor area, as listed below, are used for office, conference room, or kitchen, which are subject to the proposed plug load control requirements. The corresponding statewide floor area for these space was estimated accordingly.

- Retail - 1.0%
- Non-refrigerated Warehouse - 0.5%
- Refrigerated Warehouse - 0.5%
- School - 2%
- College - 2%
- Miscellaneous - 1%

For these spaces, we used the unit energy savings of the small office prototype, with an adjustment. We converted the unit energy savings based on building area to be based on the area of applicable spaces. Based on the detailed information provided in Appendix 9.1 for the small office building prototype, areas of spaces that are not subject plug load controls, such as corridors, mechanical/electric rooms, and restrooms, represent about 19% of the total building floor area. Therefore, the unit energy savings per applicable space area is the unit energy savings per building area divided by (1-19%), or 81%.

Detailed statewide energy savings estimate results are summarized in Figure 37.

Plug Load Category	**Plug Load Control Rates**
Task Lighting	90%
Monitor	90%
Imaging	20%
Audio /video	50%
Other	20%
Kitchen Appliance	20%

Figure 36 Estimated Rates of Plug Load Control Implementation

		Small Office	Large Office	Other Applicable NR Building Spaces	Total
Floor Area (Million SQFT)		9.09	27.7	48	84.9
Rates of Plug Load Control Implementation		70%	63%	70%	
Unit Energy Savings	**kWh/yr/SQFT**	0.49	0.61	0.61	
	kW/yr/SQFT	0.00020	0.00013	0.00017	
Statewide Energy Savings	**GWh/Year**	3.13	10.69	20.45	**34.3**
	MW/Year	1.25	2.36	5.62	**9.2**

Figure 37 Statewide Energy Savings Estimate

5. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

The CASE study investigated three levels of controls. All of them can be achieved cost effectively. Lighting control products are widely available to support field implementation. It is desirable to require the level 3 control to maximize energy savings. However, occupancy sensor control at open-space cubicles may not be easily enforced through existing office building permitting and inspection process, since many office buildings are built for future lease and do not have specific cubicle layout plan upon construction completion. Therefore, the CASE study recommends that the level 2 control, which is very similar to 2008 Title 24 general lighting control requirements, be adopted for task lighting and plug load circuit controls.

Appendix IV provides the recommended code language presented during the pre-rulemaking workshop. The original proposal recommended the addition of a subsection 131(h) to cover plug load controls. After the pre-rulemaking workshop, CEC reorganized the Title 24 Section 130 and created a new section, Section 130.5, for electrical power distribution systems. The originally proposed code language was moved into this new section. CEC also updated the plug load control requirements to include three more items:

- Section 130.5 (d) 5 clarifies that non-hardwired occupancy sensor controls are not qualified for compliance.
- Exception 1 allows the level 3 control to be used in open office spaces for compliance. The CASE study demonstrated that the level 3 control is an upgrade from the level 2 control, but it didn’t propose it as a mandatory requirement. This exception clarifies that the level 3 control can be used as a compliance option. It does not increase code stringency.
- Exception 2 exempts certain applications from plug load control. It is reasonable to exclude receptacles for wall mount clock (Exception 2 ii), for essentially communication/network equipment, and for high power equipment (Exception 2 iv) from being controlled. However, it is NOT necessary to exempt all kitchen appliances from being controlled. For example, water dispenser can be turned off during night and weekend when there is no one in the office. Moreover, the purpose of plug load control is to give building occupants/operators the capabilities to control, not require them to control. Any appliances and equipment can be plugged into an uncontrolled receptacle for non-interruption operation. The Exemption 2 could be misused to exclude all receptacles in a kitchen to be controlled so that none of the kitchen appliances can be controlled. Therefore, we recommend the exemption for water dispensers and kitchen appliances, except refrigerators, being removed. Also, A/V equipment in network rooms are only useful with presence of people and they can be controlled if desired by building occupants and it is very difficult to determine which receptacles will be used for these equipment before the building is occupied. Therefore, we recommend to remove the corresponding exception as well.

The following proposed language are based on the version of code language provided by the CEC and is based on the recommended code language proposed by the CASE study during the pre-rulemaking workshop. Additions are shown underlined and deletions are shown in strikeout.

SECTION 130.5 – ELECTRICAL POWER DISTRIBUTION SYSTEMS

(d) Circuit Controls for 120-Volt Receptacles. In all buildings, both controlled and uncontrolled 120 volt receptacles shall be provided in each private office, open office area, reception lobby, conference room, kitchen, and copy room. Controlled receptacles shall meet the following requirements:

1. **Electric circuits serving controlled receptacles shall be equipped with automatic shut-off controls following the requirements prescribed in section 130.1(c) for general lighting operating in the occupancy mode; and**
2. **At least one controlled receptacle shall be installed within 6 feet from each uncontrolled receptacle or a split-wired duplex receptacle with one controlled and one uncontrolled receptacle shall be installed; and**
3. **Controlled receptacles shall have a permanent marking to differentiate them from uncontrolled receptacles, and**
4. **For open office areas, controlled circuits shall be provided and marked to support installation and configuration of office furniture with receptacles that comply with section 130.1(a) 1, 2, and 3; and**
5. **Plug-in strips and other plug-in devices that incorporate an occupancy sensor shall not be used to comply with this requirement.**

EXCEPTION 1 to Section 130.5 (d): In open office areas controlled circuit receptacles are not required, if at time of permit workstations are installed, and each workstation is equipped with a local motion sensor that controls a power strip that is permanently marked to differentiate controlled from uncontrolled receptacles.

EXEMPTION 2 to Section 130.5 (d): Receptacles which are only for the following purposes:

- i. **In kitchens: receptacles specifically for refrigerators**~~*, water dispensers, and kitchen appliances*~~
- ii. **Receptacles located a minimum of six feet above the floor that are specifically for clocks**
- iii. **In network rooms: network copiers, fax machines,** ~~*A/V*~~ **and data equipment other than personal computers <u>and monitors</u>**
- iv. **Receptacles on circuits rated more than 20 amperes.**

6. Bibliography and Other Research

Benchmark Offices, “Office space floor plan”, http://www.benchmarkoffices.com/floorplans.htm

California Energy Commission, “Commercial Building End-Use Survey (CEUS)”, http://www.energy.ca.gov/ceus/

California Public Utility commission, “Database for Energy Efficient Resources”, http://www.deeresources.com/

Chase A.., Ramos R., Pope T., “Consumer Electronics: Market Trends, Energy Consumption, and Program Recommendations 2005-2010”, December 2006

De Chiara J., Crosbie M., “Time Saver Standard for Building Types”, 4th edition, McGraw-Hill Professional Publishing, 2000

ECOS, Office Plug Load Field Monitoring Report California Energy Commission, PIER Energy-Related Environmental Research Program, CEC-500-06-007, 2008

Kawamoto K., Koomey J., Nordman B., Brown R., Piette MA., and Meier A., “Electricity Used by Office Equipment and Network Equipment in the U.S.”, Energy Analysis Department Environmental Energy Technologies Division Ernest Orlando Lawrence Berkeley National Laboratory, LBNL-45917, August 2000

Kawamoto K., Koomey J., Nordman B., Brown R., Piette MA., Ting M., Meier A., “Electricity Used by Office Equipment and Network Equipment in the U.S.: Detailed report and appendices”, Energy Analysis Department Environmental Energy Technologies Division Ernest Orlando Lawrence Berkeley National Laboratory, LBNL-45917, February 2001

National Electrical Installation Standards, “All NEIS Standards”, http://www.neca-neis.org/standards/

National Fire Protection Association, “NFPA 70 : National Electrical Code”, Codes & Standards, , http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=70

Roberson J., Homan G., Mahajan A., Nordman B., Webber C., Brown R., McWhinney M., Koomey J., “Energy Use and Power Levels in New Monitors and Personal Computers”, Energy Analysis Department Environmental Energy Technologies Division Ernest Orlando Lawrence Berkeley National Laboratory, LBNL-48581, July 2002, http://enduse.lbl.gov/Projects/OffEqpt.html

Roberson J., Webber C., McWhinney M., Brown R., Pinckard M., and Busch J., “After-hours Power Status of Office Equipment and Energy Use of Miscellaneous Plug-Load Equipment”, LBNL-53729-Revised, May 2004

Roth K., Goldstein F., Kleinman J., “Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings Volume I: Energy Consumption Baseline”, prepared for Office of Building Equipment Office of Building Technology State and Community Programs, January 2002

Roth K., Goldstein F., Kleinman J., “Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings Volume II: Energy Savings Potential”, prepared for Building Technologies Program, December 2004

Sanchez M. Webber C., Brown R., Busch J., Pinckard M., Roberson J., “Space Heaters, Computers, Cell Phone Chargers: How Plugged In Are Commercial Buildings?”, Environmental Energy Technologies Division Ernest Orlando Lawrence Berkeley National Laboratory University of California , February 2007

SmartDraw Communicate Visually, “Easy floor plan software”, http://www.smartdraw.com/specials/floorplans.asp

Southern California Edison, Design and Engineering Services, “Office of the Future Phase II Report The 25% Solution”, Prepared for: The Office of the Future Consortium: Design and Engineering Services, Southern California Edison; Pacific Gas & Electric; Sempra Energy; Sacramento Municipal Utility District; Consolidated Edison; National Grid; NSTAR; BC Hydro; U.S. Department of Energy, January 2002

The WattStopper, “Lighting control best practice guide: Office Buildings”, http://www.nxtbook.com/nxtbooks/wattstopper/officebuildingsbpg08/

Webber C., Roberson J., Brown R., Payne C., Nordman B., Koomey J., “Field Surveys of Office Equipment Operating Patterns”, Energy Analysis Program Environmental Energy Technologies Division Lawrence Berkeley National Laboratory, LBNL-46930, September 2001, http://enduse.lbl.gov/Projects/OffEqpt.html

7. Appendix I: ASHRAE and IgCC Plug Load Control Standards

This section presents the ASHRAE 90.1 and the International Green Construction Code (IgCC) language regarding plug load controls.

7.1 ASHRAE 90.1

The ASHRAE Lighting Subcommittee developed CMP to 90.1-2007, modifying Addendum "bs"section 8.4.2, labelled "Automatic Receptacle Control". The revised language is as follows:

> "At least 50% of all 125 volt 15- and 20-Ampere receptacles, including those installed in modular partitions, installed in the following space types:
>
> > Private offices
> >
> > Open offices
> >
> > Computer Classrooms
>
> shall be controlled by an *automatic control device* that shall function on:
>
> > a. a scheduled basis using a time-of-day operated control device that turns receptacles off at specific programmed times - an independent program schedule shall be provided for areas of no more than 25,000 ft2 but not more than one floor - or
> >
> > b. an *occupant sensor* that shall turn receptacles off within
> >
> > 30 minutes of all occupants leaving a space or
> >
> > c. a signal from another control or alarm system that indicates the area is unoccupied.
>
> **Exceptions:** Receptacles for the following shall not require an *automatic control device:*
>
> > Receptacles specifically designated for equipment requiring 24 hour operation.
> >
> > Spaces where an automatic shutoff would endanger the safety or security of the room or building occupant(s)."

7.2 International Green Construction Code (IgCC)

The IgCC also developed plug load control requirements. This is a technical requirement which doesn't specify implementation means. It was thought rather in the framework of soft-wire control technologies such as timer or occupancy sensor on plug strips or smart strips rather than hard wiring control technologies. The code language is the following:

"609.6 Plug load controls. Receptacles and electrical outlets controlled by an *occupant sensor* or *time switch* shall be provided in accordance with all of the following:

> 1. In Group B office spaces without furniture systems incorporating wired receptacles, at least one switched receptacle shall be provided for each 50 square feet.

2. In Group B office spaces with furniture systems incorporating wired receptacles, at least one switched circuit shall be provided at each electrical outlet used for powering furniture systems.

3. In classrooms in Group B and Group E occupancies, at least four switched receptacles shall be provided in each classroom.

4. In copy rooms, print shops, and computer labs, not less than one switched receptacle shall be provided for each data jack.

5. In spaces with an overhead cabinet above a counter or work surface, not less than one switched receptacle shall be provided for each work surface.

609.6.1 Distribution and marking. Controlled receptacles and electrical outlets shall be distributed in a reasonably uniform pattern throughout each space. Controlled receptacles shall be marked to differentiate them from uncontrolled receptacles.

609.6.2 Furniture systems. Furniture systems incorporating wired receptacles shall include at least two receptacles at each workstation that are connected to a controlled circuit.

609.6.3 Computer office equipment. Computer monitors, plug in space heaters, air purifiers, radios, computer speakers, coffee makers, fans, and task lights located in spaces with controlled receptacles shall be plugged into controlled receptacles.

609.6.4 Audio and visual systems. Displays, projectors, and audio amplifiers in Group B and Group E classrooms, conference and meeting rooms, and multipurpose rooms shall be controlled by an *occupant sensor*.

609.6.5 Water dispensers. Water dispensers that utilize energy to cool or heat drinking water shall be controlled by *time switch controls*.

609.6.6 Refrigerator and freezer cases. Lighting integral to vending machines and refrigerator and freezer cases shall be controlled by an *occupant sensor* or a *time switch*."

8. Appendix II: Industry Practice Survey

This section is presenting the online surveys sent to electrical designer, electrical contractor and system furniture manufacturers.

8.1 CASE Office Task Lighting and Plug Loads, Designer and Contractor survey

8.1.1 Survey Form

The California Investor Owned Utilities (IOUs) are actively supporting the California Energy Commission (CEC) in developing the state's building energy efficiency standard (Title 24, Part 6). Their joint intent is to achieve significant energy savings through the development of reasonable, responsible, and cost-effective code change proposals for the 2011 code update. Codes and Standards Enhancement (CASE) Studies are conducted by IOUs to assess technical potential, cost-effectiveness, and feasibility of proposed regulation improvement.

The Office Tasking Lighting Control CASE study aims to develop requirements of automatic controls of task lighting and other plug loads. Possible control strategies include central timer controls of task lighting/plug load circuits or occupancy sensor controls at individual work station/private office.

As part of the CASE study effort, we invite you to fill out this survey to provide necessary information to guide the code change development. The following questions are related to office space electrical wiring design practices and challenges associated with plug load controls. Intended audience for this survey is office building electrical system designers and contractors.

General Information

1. Please select the profile(s) that best describes you:

- ☐ Designer / Electrical Engineer
- ☐ Contractor
- ☐ Other (please specify)

2. How many office electrical wiring design/installation projects have you worked on?

- ☐ More that 100
- ☐ 50 – 100
- ☐ 10 – 50
- ☐ Less than 10

3. What geographic areas do you serve (check all areas that apply):

- ☐ North Coast
- ☐ Sacramento area
- ☐ Bay area
- ☐ Central Valley
- ☐ Central Coast
- ☐ Los Angeles area
- ☐ San Diego area

Wiring Practice

To implement task lighting and plug load controls, workstations/private offices need to be supplied with more than one independent circuit so that essential office equipment, e.g. computers, fax machines, can be connected to a circuit that will not be interrupted while other plug load circuits are controlled.

4. In how many projects did you bring two or more independent circuits to a private office?

- ☐ more than 75%
- ☐ 50 - 75%
- ☐ 25 - 50%
- ☐ less than 25%

Comments

5. In how many projects did you bring two or more independent circuits to a workstation (cubicle)?

- ☐ more than 75%
- ☐ 50 - 75%
- ☐ 25 - 50%
- ☐ less than 25%

Comments

6. Is it a preferred practice to bring at least two independent circuits to a workstation/private office?

- ☐ Yes, always
- ☐ No, it doesn't really matter
- ☐ It depends

If it depends, please explain

Plug load control strategies

The CASE study plans to propose task lighting and plug load control requirements based on two types of control strategies, central timer controls and local occupancy sensor controls. The former will be installed at circuit breaker/control panel to turn off circuits for task lighting and non-essential plug loads during certain non-business hours. A manual override will be provided. The latter can be implemented at each cubicle and private office to achieve maximum electricity consumption reduction.

In both strategies, circuits for essential office equipment will not be controlled.

7. Are there any issues associated with central timer controls of task lighting and plug load?

8. Are there any issues associated with local occupancy sensor controls of task lighting and plug load?

9. In how many projects did you design/install these task lighting/plug load control strategies in office buildings?

Control Type	Never	1 - 5	5 - 10
Central timer control			
Local occupancy sensor			

10. What other control strategy(ies) would you recommend?

11. Please provide any comment or concern not covered by the previous questions.

12. Providing contact information is always optional. All survey results will always remain anonymous, but if our CASE authors have follow up questions, they would like to be able to contact you.

Name:

Company:

Email Address:

Phone Number:

8.1.2 Survey Answers

Respondent Profile

The pool of electrical designers and contractors surveyed was diversified. Half of the respondents were electrical designers, while the other half were electrical contractors, operating in every area of California. The total number of participants was 12. Half of them have worked on more than 100 office wiring projects, and 65% have worked on more than 50 office wiring projects. The other respondents were also experienced in office wiring (they worked on 10 to 50 office wiring projects).

Wiring practice

Bringing two separate circuits to a private office is done in about a quarter of the office projects wired this way. The main reason for feeding private offices with only one circuit is typically budget constraint. The general rule for private office wiring is to bring 3 circuits to feed 3 to 4 offices. Workstations in open spaces are very rarely served by two independent circuits (only 25% of them are). Most of the respondents agreed that bringing two circuits to a private office or a workstation is a better practice. They argued that it provides flexibility in terms of which equipment can be used at the workstation, and that putting computers and printers on a separate circuit is preferable.

Circuit Controls

No major concerns were voiced about implementation of time switch controls for task light and plug control. Designers and contractors noted that some circuits would have to remain uncontrolled. Some stressed that this solution may not be widely adapted for businesses which require flexibility, for instance businesses not on a 8am-5pm schedule, or when some workstations need to be switched on while others can be turned off. One respondent was worried about additional cost and complexity while doing business in California, and would rather see this requirement adopted at the federal level.

Apart from cost concerns, comments on the occupancy sensor control strategy are related to implementation considerations. Survey respondents stressed the importance of the equipment quality, in order to detect slight movements and adjust the time delay to avoid disruption. They also suggested that the receptacles would have to be color-coded, and that clocks and some other equipment would have to remain uncontrolled.

While there was little resistance to this proposal, these strategies are not commonly put into practice in the field. Forty two percent (42%) of the respondent replied having experience installing central timer control for office plug loads. The occupancy strategy seemed more common, as 67% of respondents reported having experience with it in office spaces.

In addition to applying central control or occupancy control, some respondents recommended using personal controlled outlet (with either a timer or an occupancy sensor) or occupancy sensor integrated into the task light to avoid wiring configuration change as alternatives.

8.2 CASE Office Task Lighting and Plug Loads, System furniture manufacturer survey

8.2.1 Survey Form

The California Investor Owned Utilities (IOUs) are actively supporting the California Energy Commission (CEC) in developing the state’s building energy efficiency standard (Title 24, Part 6). Their joint intent is to achieve significant energy savings through the development of reasonable, responsible, and cost-effective code change proposals for the 2011 code update. Codes and Standards Enhancement (CASE) Studies are conducted by IOUs to assess technical potential, cost-effectiveness, and feasibility of proposed regulation improvement.

The Office Tasking Lighting Control CASE study aims to develop requirements on automatic controls of task lighting and other plug loads. Possible control requirements include central timer controls of task lighting/plug load circuits and occupancy sensor controls at work station/private office levels.

As part of the CASE study effort, we invite you to fill out this survey to provide necessary information to guide the code change development. The following questions are related to office workstation wiring and design practices in California, as well as strategies of task lighting/plug load controls. Intended audiences for this survey are system furniture manufacturers, distributors, and office furniture system designers.

General Information

1. Please select the type of system furniture you manufacture/sell/specify:

- ☐ New
- ☐ Refurbished
- ☐ Both

2. Please select the area(s) which best defines the geographic area(s) you serve:

- ☐ North Coast
- ☐ Sacramento area
- ☐ Bay area
- ☐ Central Valley
- ☐ Central Coast
- ☐ Los Angeles area
- ☐ San Diego area

3. What percentage of your system furniture is delivered with attached task lighting fixtures (under cabinet lighting or other types)?

- ☐ More than 75%
- ☐ 50% - 75%
- ☐ 25% - 50%
- ☐ less than 25%

Comments

System Furniture Wiring Practices

To implement task lighting and plug loads controls, workstations need to be supplied with more than one independent circuit so that essential office equipment, e.g. computers, fax machines, can be connected to a circuit that will not be interrupted while other plug load circuits are controlled.

4. What percentage of furniture is installed with at least two independent circuits brought to a workstation?

	more than 75%	50% -75%	25% - 50%	less than 25%
Cubicles furniture				
Private office furniture				

NA (please specify)

5. Do you usually recommend to have more than one circuit connected to a workstation, without considering task lighting and plug load control?

- ☐ Yes
- ☐ No
- ☐ It depends on application

If depends on application, please specify

6. For the system furniture you are providing, do you label receptacles to differentiate the circuits they are connected to?

- ☐ Yes, if multiple circuits are to be connected to the system furniture
- ☐ Yes, upon customer requests
- ☐ No

Comments:

Workstation Occupancy Sensor Control

Occupancy sensor control at workstations can help to maximize the reduction of electricity consumption by task lighting and office plug loads. Operation of essential office equipment will not be controlled.

7. Do you provide system furniture that is equipped with occupancy sensor control or can be configured to allow occupancy sensor control?

	Yes, we are providing such system furniture	Not now, but we plan to provide such system furniture in the near future	No, we don't plan to provide such system furniture
New system furniture			
Refurbished system			

Comments

8. What percentage of the system furniture you delivered was working with occupancy sensors?

- ☐ more than 30% of the delivered system furniture
- ☐ 20 - 30%
- ☐ 10 - 20%
- ☐ 5 - 10%
- ☐ less than 5%

Comments

9. Are there any issues related to implementing occupancy sensor controls in office system furniture?

10. What other control strategy(ies) would you recommend for office task lighting and plug load controls in offices?

11. Providing contact information is always optional. All survey results will always remain anonymous, but if our CASE authors have follow up questions, they would like to be able to contact you. Thank you!

Name:

Company:

Email Address:

Phone Number:

9. Appendix III: Office Building Prototypes

This section presents detailed information on the two office prototypes developed for this case study. These prototypes were developed to overcome limitations of the CASE analysis prototypes. They are based on the DEER (Database for Energy Efficient Resources) office building models. The same assumptions regarding office prototype physical shape, occupant density, and building space activity breakdown are kept, and a space layout was created based on these inputs and some typical office space layouts.

9.1 Small Office

The DEER small office building prototype used for energy savings and cost-effectiveness calculation is a two-story 10,000 sf building, with a rectangular footprint (50ft×100ft). Based on the space breakdown in Figure 38, it was estimated that the office building could host 33 occupants. The first floor is made of a lobby with reception desk, stairs and elevator, a large open-space with 6 cubicles in the building core surrounded by 9 private offices and a conference room located at the perimeter of the building. The restrooms, copy room, kitchen and mechanical room can be found along the building perimeter. The first floor hosts 15 occupants. The second floor has a similar configuration, with an additional cubicle in the core of the building, hence hosting 16 employees. The floor layout, shown in Figure 39, was developed based on common office floor plans and was checked by registered architects.

Office Areas (Private office and open-space cubicle)	70%
Corridor	10%
Lobby	5%
Conference Room	4%
Copy Room	2%
Restrooms	5%
Mechanical/Electrical Room	4%

Figure 38 Small Office Area Breakdown

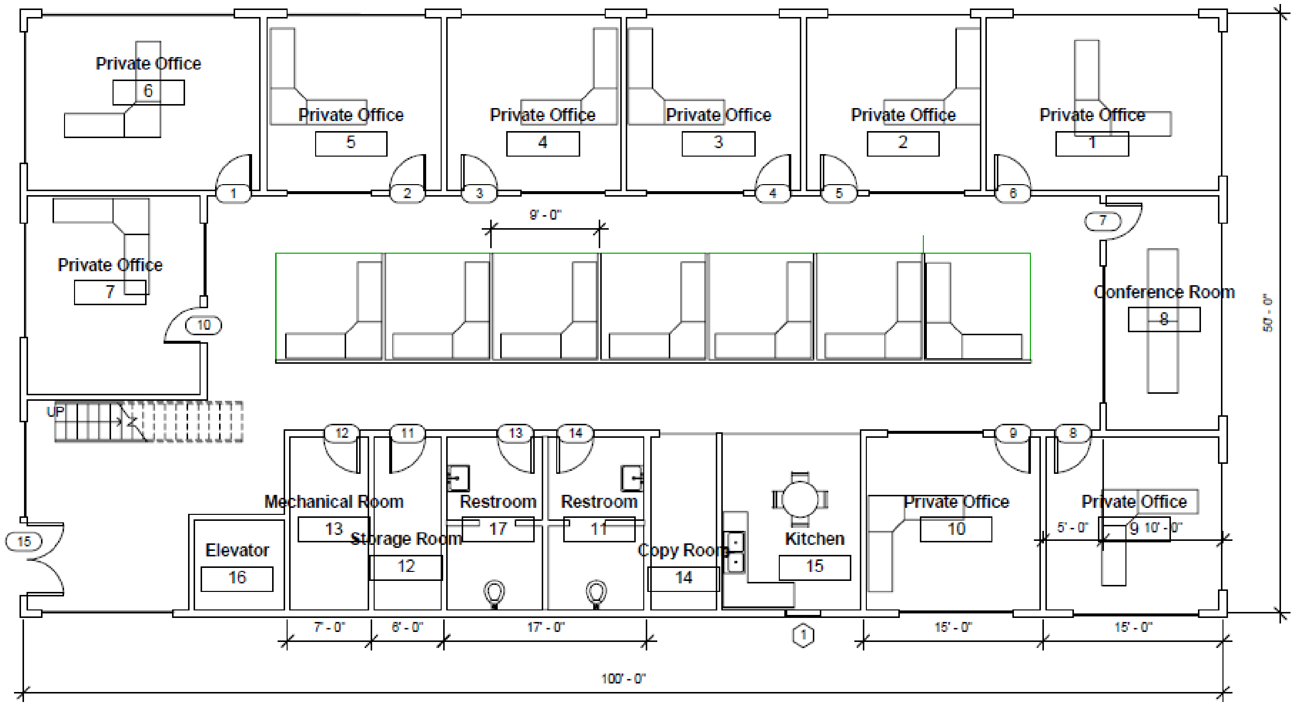


Figure 39 Small Office Floor Plan

9.2 Large Office

The DEER prototype building used for energy savings and cost-effectiveness analysis purpose is a 10 story 175,000 sf building. Its shape is rectangular (175ft×100ft), and all floors have a similar layout. Based on the space breakdown in Figure 40 and floor plan in Figure 41, it was assumed that the building would host seven hundred and thirty (730) people. Each floor hosts seventy-three (73) employees. A typical floor is made of 19 private offices, 54 cubicles, 2 conference rooms, 2 copy rooms, kitchen and restrooms. Each East and West perimeters host 10 private offices and a large conference room while the North and South perimeter spaces are open offices with 27 cubicles in stack of 6 or 3 at each orientation. A lobby with elevators and stairs is located in the building core, with kitchen, mechanical room and restroom on both sides. Another 9 private offices can be found in the building core. The office layout was developed based on the office buildings floor plan provided in the WattStopper "Lighting control best practice guide: Office Buildings" and were checked by a registered architect.

Office Areas (Private office and open-space cubicle)	70%
Corridor	10%
Lobby	5%
Conference Room	4%
Copy Room	2%
Restrooms	5%
Mechanical/Electrical Room	4%

Figure 40 Large Office Area Breakdown

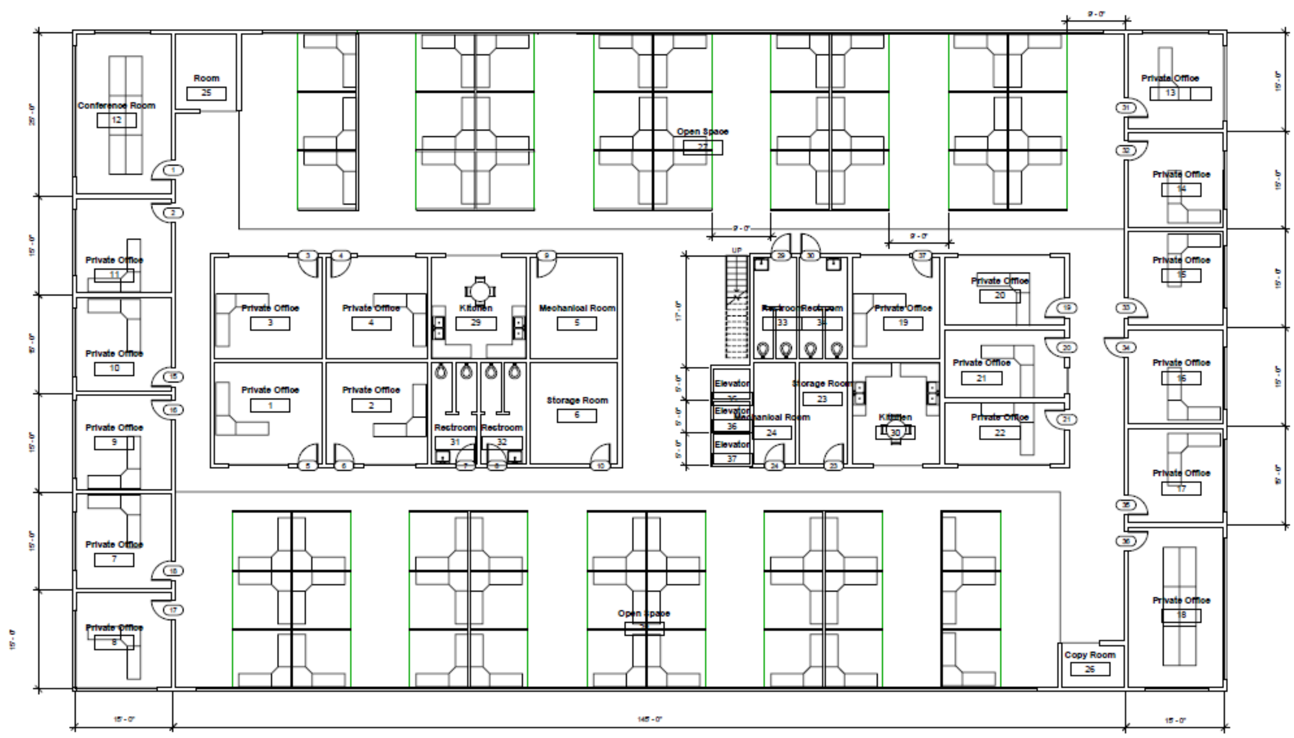


Figure 41 Large Office Floor Plan

10. Appendix IV: Recommended Code Language Provided during the Pre-Rulemaking Workshop

SECTION 131 – INDOOR LIGHTING CONTROLS THAT SHALL BE INSTALLED

(h) Task lighting. In all buildings, both controlled and uncontrolled receptacles shall be provide in each private office, open office space, conference room, kitchen, and copy room. Controlled receptacles will allow automatic shut off control of connected task lighting and plug loads. Controlled receptacles shall meet the following requirements:

1. Electric circuits serving controlled receptacles shall be equipped with automatic shut-off controls following the requirements prescribed in section 131(d) for general lighting; and

2. At least one controlled receptacle shall be installed within 1 foot from each uncontrolled receptacle or a split-wired duplex receptacle with one controlled and one uncontrolled receptacle shall be installed; and

3. Controlled receptacles shall have a permanent marking to differentiate them from uncontrolled receptacles, and

4. For open office spaces, controlled circuits shall be provided and marked to support installation and configuration of office furniture with receptacles that comply with section 131 (h) 1, 2, and 3.

11. Appendix V: Material Impact Estimation

The proposed change will increase the use of electrical components, including circuit relays, occupancy sensors, electric wires, and controls. Section 4.6 provides very detailed specifications of circuit system improvement to accomplish the proposed control requirements. Figure 42 provided estimate material use for each types of electrical components. Total building material impacts for the two prototype buildings were calculated according to the increasing in electrical components listed in Figure 27 and **Error! Reference source not found.**. Unit material impacts were calculated as material impact per unit rea of building floor area. The statewide material impacts were calculated by multiply unit material impact by statewide construction forecast of office spaces, listed in Figure 37.

	Mercury	Lead	Copper	Steel	Plastic	Others (Identify)
Per Component						
Occupancy sensor (lb)	0.0005	0.0025	0.15	0.1	0.25	0
#12 power wiring, 100' (lb)	0	0	2	0	0.2	0
Relay (lb)	0	0.00125	0.3	0.1	0.25	0
Control panel upgrade (lb)	0.005	0.025	1.5	1	2.5	0
Small Office						
per building (lb)	0.015	0.08	156	3.4	23.5	0
per floor area (lb/sqft)	0.0000015	0.0000080	0.0156	0.00034	0.00235	0
Large Office						
per building (lb)	0.155	0.863	2568	38	345	0
per floor area (lb/sqft)	0.00000089	0.0000049	0.0147	0.00022	0.0020	0
Statewide	110	590	1,300,000	25,000	189,000	0

Figure 42 Material Impact Estimation